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HELICOPTER AIR-TO-AIR COMBAT TEST IV (AACT IV) MANEUVERABILITY ANALYSIS

G. Thomas White and Donald A. Skrinjorich

July 1992

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13. ABSTRACT *(Maximum 200 words)* This report presents the data and findings from the AACT IV flight test program sponsored by AATD. One-on-one air-to-air combat tests of the AH-1S Cobra, AH-64A Apache, SA-365N-1 Dauphin, and 406 Combat Scout helicopters were conducted for maneuverability and agility effectiveness. The tests were flown at the Naval Air Test Center (NATC), Patuxent River, Maryland, from 22 March to 30 April 1987. Flights performed totaled 18, with 22 hours of productive flight time. Total NATC on-site flight time was approximately 87 hours, including instrumentation check flights, maintenance flights, one-on-one familiarization flights, and data flights. The performance of the aircraft involved in AACT IV and analysis of their contributions in an air-to-air environment are discussed. Air vehicle subsystems and other vehicle flight test configuration initiatives used in AACT IV are also described. The AACT IV general findings include: (1) cockpit field of view should be unobstructed and as extensive as possible; (2) time to turn should be minimized for best air combat maneuvering (ACM) performance; (3) high specific excess power at mission weight is necessary for increased maneuverability; (4) the pilot should be given full ACM potential without constant attention to envelope limits; (5) turreted weapons provide added kill probability but do not mitigate maneuverability, and (6) the performance characteristics of teetering rotor systems during ACM are not conducive to the close-range air-to-air environment. A major shortcoming of the test program was the lack of consistent laser weapon simulator ballistic hit/miss and aiming error quantitative data.

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PREFACE

The work reported herein was managed by the U.S. Army Aviation Applied Technology Directorate (AATD), Fort Eustis, Virginia, and covers testing activity during April 1987. The series of air-to-air combat tests (AACT I, II, III, and IV) composes the flight test element of AATD's Helicopter Maneuverability Program, which also includes both analysis and simulation elements. This maneuverability program, begun in 1983, was conceived by Mr. Duane R. Simon, who provided technical direction until his retirement from AATD in 1988.

LTC Waldo Carmona of AATD made major contributions to this report by consolidating the AACT pilot observations and reviewing the report's technical content. Mr. Ron Bowman provided the extensive still photographic records contained herein as well as video reports of the entire AACT IV activity. Mr. Tommy Wiggins assisted in the preparation of several appendixes presented in the report.

In addition, the following AATD personnel are commended for their outstanding contributions in the preparation of the AH-1S Cobra and the SA-365N-1 Dauphin, as well as their technical support during AACT IV:

Stan Aiton	Steve Morgan
Bob Bessette	Norris Paxson
Ron Bott	Frank Reisbeck
Terry Coffelt	Gary Webb
Wayne Foster	Al Whiting
John Hayth	Al Williamson

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INTRODUCTION

BACKGROUND

In response to the ever-increasing threat of armed helicopters, the U.S. Army initiated a counter-air program to elevate the Army's preparedness in the air-to-air environment. Tactical training of pilots in helicopter air-to-air combat was instituted as per FM 1-107, Air-to-Air Combat.[1] The assessment of current helicopter air combat capabilities through the Air-to-Air Combat (ATAC) testing (Directorate for Combat Developments, Fort Rucker), the Air-to-Air Combat Tests (AACT) (Aviation Applied Technology Directorate (AVSCOM), Fort Eustis), and the Helicopter Air Combat (HAC) simulation (Aeroflightdynamics Directorate (AVSCOM), NASA Ames Research Center) is ongoing. Multidisciplined research and development investigations are also underway to provide current and future rotorcraft with the weapons, sensors, and airframe performance capabilities necessary to engage and survive in air-to-air combat.

Aircraft combat survivability can be divided into two categories: vulnerability and susceptibility.[2] Vulnerability refers to the inability of an aircraft to withstand serious damage or destruction when hit by enemy fire. Susceptibility refers to the inability of an aircraft to avoid being damaged in the pursuit of its mission, that is, to its probability of being hit. The level or degree of susceptibility of an aircraft in a given encounter with a threat is dependent upon three major factors: the scenario, the threat, and the aircraft. Since the specific scenario and threat cannot be predesignated in any real-world situation, the susceptibility can only be quantitatively affected prior to an engagement by the alteration of aircraft design characteristics. The important factors associated with the aircraft itself, excluding its weapon suite, include aircraft observables or detectable signatures, any countermeasures used, self-protection armament, and the aircraft performance (i.e., maneuverability and agility (M&A) capabilities).

All of the concepts for susceptibility reduction except some aspects of signature reduction and tactics involve some piece of equipment, device, or armament that is carried either by the aircraft for self-protection or by another special-purpose aircraft in a support role. One element in the probability of hit (P_h) equation--the probability of detection, identification, and tracking--can be reduced by tactics that employ either terrain masking or evasive maneuvering. Inherent aircraft capability in terms of M&A is the chief contributor to the offensive or the defensive tactics that can be effectively employed to reduce susceptibility.

In an air-to-air engagement or a low altitude interdiction mission, the helicopter is exposed to a threat scenario which may defeat the protection afforded by aircraft survivability equipment (ASE), armor, or threat warning devices. The solution to surviving such an encounter may depend upon the extent of the maneuvering

performance envelope available to elude or out-maneuver the threat or if necessary, to bring self-defense weapons to bear to defeat the threat.

For the air combat maneuver (ACM) rotorcraft, maneuvering performance equals maneuverability plus agility. Maneuverability may be measured in terms of turn rate, climb rate, acceleration, and load factor; agility is addressed in terms of damping, pilot workload, aircraft positioning precision, and time to maneuver.

The AACT program consisted of a series of engineering flight tests conducted by the AATD which placed various Army fleet "mainstay," as well as state-of-the-art, helicopters in a one-on-one ACM environment. The tests simulated the air-to-air combat that would result from gunnery encounters between two helicopters at a close range. Flown at the Patuxent River Naval Air Test Center, Maryland (Figure 1), the tests were structured to evaluate the M&A of the participating aircraft, to establish an engineering data base for understanding the contribution of key design parameters to ACM, and to develop M&A requirements for future helicopters designed for the air-to-air mission. These tests were not designed to formulate tactics and were not purely a comparison of one aircraft against another to determine a "winner."

The first test, AACT I, was flown in April 1983 using a Bell OH-58A "Kiowa" and a Bell AH-1S (PROD) "Cobra" aircraft. The objective of AACT I was to develop and validate techniques for airborne instrumentation, aircraft ACM radar-tracking, data processing, and evasive maneuvering. AACT I was also intended to show that tests of this nature could be safely performed and meaningful engineering data could be collected.

The second test, AACT II, was flown in July 1983 using three aircraft: a Sikorsky UH-60A "Blackhawk", a Sikorsky S-76 (armed utility version, also known as AUH-76), and a Bell OH-58A. The primary objective of AACT II was to establish a data base on maneuvering performance of helicopters with different design characteristics. Other specific objectives included indication of rotorcraft maneuverability advantages, quantitative indication of laser versus radar tracking accuracy, implementation of established data analysis procedures, incorporation of Marine Air Weapons and Tactics Squadron (MAWTS) evasive maneuvering (EVM) techniques, and compilation of data for maneuver simulation software validation.

The third test, AACT III, was flown in December 1984 using four aircraft: a McDonnell Douglas 530 (formerly Hughes H-530), a Bell OH-58A, a Bell AH-1S (MOD), and a Messerschmidt Bolkow-Blohm (MBB) BK-117. The purpose of AACT III was to expand the one-on-one data base, refine the flight test methodology, obtain teetering rotor flapping spectrum data, and obtain gun firing opportunity data via laser weapons simulators (LWSs)(fixed forward gun only).

AACT IV is the latest in this series of tests and was flown in April 1987. Close-in "fights" were simulated with fixed and turreted guns emulated by an LWS as well as long-range

and short-range encounters involving a helicopter equipped with a Stinger captive flight trainer missile. The AACT IV objectives are discussed in detail in the following section.

The aircraft used in the AACT program and the total flight time on the data range for the individual tests are as follows:

AACT I (April 1983)	4.5 hours
OH-58A	
AH-1S (Bell metal blades)	
AACT II (July 1983)	12.0 hours
OH-58A	
AUH-76	
UH-60A	
AACT III (November 1984)	15.0 hours
OH-58A	
AH-1S (Kaman composite blades)	
HHI 530MD	
MBB BK-117	
AACT IV (April 1987)	22.0 hours
AH-1S (Bell metal blades)	
AH-64A	
BHT 406 CS	
SA-365N-1	

The OH-58A was initially the baseline or common aircraft for each test; however, after AACT II the AH-1S was designated the baseline aircraft. AACT IV consisted of the AH-64A Apache, AH-1S Cobra, Bell 406 Combat Scout (CS), and Aerospatiale SA-365N-1 Dauphin. Several unique systems were used on the AACT IV aircraft. A new LWS was employed on the Cobra, Combat Scout, and Dauphin. A laser system similar to that used by the BK-117 and H-530 in AACT III was installed on the Apache. In the previous AACTs, only grease pencil cross-hairs on the wind screen were used. For AACT IV, an electromagnetic helmet-mounted sight (HMS) was installed in both the 406 CS and the AH-1S. This system was intended to direct the turrets on these aircraft. A heads-up display (HUD) unit was integrated with the laser system on the Dauphin while a similar pilot display unit (PDU) was used on the 406 CS for the Stinger missile captive flight train flights. The Apache employed the existing onboard fire control system and integrated the LWS with this system.

TEST OBJECTIVE

The objective of AACT IV was to complete the airframe M&A data base created by AACTs I, II, and III by introducing current state-of-the-art aircraft. Specific objectives were:

1. To further refine the flight test methodology.

2. To assess the ACM attributes of the AH-1S, the SA-365N-1, the 406 CS, and the AH-64A.

3. To measure the ACM effectiveness of the AH-64A "manual" Integrated Helmet and Display Sight System (IHADSS) versus the "auto" Target Acquisition and Designation System (TADS).

4. To obtain flapping spectrum data in air-to-air engagements for the AH-1S helicopter with hub spring.

5. To obtain both fixed (with HUD) and turreted (with HMS) gun firing opportunity data, including aiming and hit/miss error data as well as aircraft pointing and positioning data via LWSs.

6. To measure helicopter maneuvering conditions during simulated air-to-air missile target acquisition, tracking, and launch.

7. To document the effects of ACMs on structural loads.

8. To identify the ACM performance attributes of the Fenestron fan-in-fin directional control device.

9. To explore basic single-ship M&A performance capabilities of the SA-365N-1, the 406 CS, and the AH-64A.

This flight investigation was conducted in accordance with appropriate airworthiness and safety-of-flight releases for the subject aircraft and with an approved AACT IV Flight Test Plan.[3]

DESCRIPTION OF TEST AIRCRAFT

The four aircraft flown during the AACT IV were the AH-1S, AH-64A, SA-365N-1, and 406 CS. Detailed descriptions of the test aircraft external and internal configuration elements peculiar to the AACT are contained in Appendix A. Each aircraft as configured for the test is described below.

The AH-1S (Figure 2) is a U.S. Army attack helicopter (designated JAH-1F as modified for flight test). The aircraft used in this test, tail number 76-22600 (Figure 3), was equipped with the Bell 540 rotor blades and was assigned to the AATD. Bell Helicopter Textron Inc. (BHTI) instrumented the aircraft and AATD provided the instrumentation data recording package and the flight test support team. The AH-1S is described in detail in the Operator's Manual.[4] The aircraft was instrumented for handling qualities and performance parameters via pulse code modulation (PCM) data recording and telemetry as well as for structural loads parameters. Special modifications included an electromagnetic HMS (replacing the production Helmet Sight Subsystem (HSS)), an eye-safe LWS on the 20mm gun turret, laser reflectors on both wing tips, a hub spring, cockpit aural and visual main rotor flapping angle and low "g" indicators, a collective stick shaker, external video fixed and turreted "gun" cameras, a video monitor in the copilot station, "puffed cheek" ammo (instrumentation) bay doors, and a transponder for radar space positioning. The standard HUD and telescopic sighting unit (TSU) were on board but not operational. Grease pencil aiming pippers on the HUD glass provided target sighting alignment for the LWS in the fixed gun mode.

The AH-64A (Figure 4) is a U.S. Army attack helicopter. The vehicle used in this test was aircraft PV 02, tail number 82-23356 (Figure 5). The aircraft was loaned to AATD by the AH-64A Project Manager's Office for use in this test. McDonnell Douglas Helicopter Company (MDHC) provided the flight crew and flight test support team and served as the contractor to AATD for the instrumentation package. This aircraft is described in detail in the Operator's Manual.[5] The AH-64A was instrumented for handling qualities, performance, and structural loads data. The aircraft had external dummy stores and was fitted with an eye-safe LWS in place of the 30mm turreted gun. The aircraft was also equipped with internal (cockpit) and external cameras plus laser reflectors on both wing tips, and a transponder for radar space positioning. The IHADSS and TADS were employed for turreted gun aiming, while a fixed forward reticle on the helmet-mounted display (HMD) as well as grease pencil cross-hairs on the cockpit blast shield and forward canopy panel were explored for rudimentary fixed gun sighting of the LWS. Also, the pilot station instrumentation panel side glare shields were removed for better out-of-cockpit visibility.

The SA-365N-1 (Figure 6) is a commercial aircraft manufactured by Aerospatiale Helicopter Company (AHC) of France. The aircraft used, serial number 6011 (Figure 7), was leased from AHC, Grand Prairie, Texas, with funds supplied by the U.S. Army

Foreign Science and Technology Center (FSTC). AATD installed the data recorder package and operated the aircraft. The SA-365N-1 was equipped with a flying qualities and performance PCM package and an abbreviated structural loads package. The aircraft is described in detail in the Flight Manual.[6] The aircraft was modified to include an eye-safe LWS (fixed forward only), laser reflectors on both sides and on the bottom of the fuselage, a HUD unit at the pilot's station for fixed gun aiming, an external video "gun" camera, ballast containers, a video monitor in the copilot's station, and a radar transponder.

The 406 CS flown in this test was serial number 2500, tail number N2500B (Figures 8 and 9). The aircraft was manufactured, provided, and supported by BHTI. This aircraft is described in detail in the experimental 406 CS Flight Manual.[7] It was instrumented with a flying qualities and performance PCM and structural loads package. The aircraft was equipped with a turreted eye-safe LWS, laser reflectors on both sides of the pylon and bottom of the fuselage, an air-to-air Stinger captive flight trainer missile, a HUD unit (for missile only), an electromagnetic HMS system, external video cameras, and a radar transponder. A single grease pencil pipper on the pilot's windscreen provided for rudimentary fixed gun alignment. (Note: Integration malfunction between the helmet sight system and the turret prevented use of the "gun" in the fully turreted mode.)

ACM TESTING

SCOPE

The ACM testing was conducted at the Patuxent River Naval Air Test Center (NATC), Maryland, between 22 March and 30 April 1987. Three basic types of maneuver scenarios were performed by the participating helicopters: single aircraft agility maneuvers, dual aircraft structured engagements (as per FM 1-107), and dual aircraft free engagements.

The single aircraft agility maneuvers were performed in order to accomplish two objectives: to acquire data for validation of the Maneuver Criteria Evaluation Program (MCEP)[8] and other similar simulation codes, and to document basic aircraft M&A characteristics. The maneuvers devised to assess vehicle M&A consisted primarily of:

1. Longitudinal and lateral acceleration/deceleration
2. Rearward acceleration
3. Climb/descent
4. Turn at constant airspeed and altitude
5. Control step inputs
6. Roll reversal
7. Return to target
8. Pull-ups and pushovers

The dual aircraft structured engagements were one-on-one warm-up maneuvers based on the training guidelines given in the Army Air-to-Air Combat Field Manual.[1] These prescribed or "canned" one-on-one engagements were of a structured format with one attacker aircraft versus one "passive" bogey aircraft. These engagements served to familiarize each flight crew with the mobility characteristics of the other aircraft as well as to condition or "calibrate" the crews for operating their aircraft in close proximity with another vehicle prior to commencement of the free engagements. The one-on-one training/buildup flights also served to refine the flight cards subsequently used in the free engagement data flights. The warm-up maneuvers consisted of:

1. Tail chase, including high yo-yo, low yo-yo, and horizontal scissors
2. Head-to-head passes, including level turns, wingovers, and pop turns (climbing turns)

The dual aircraft free engagements were performed from given initial conditions of airspeed, altitude, and relative heading with respect to the other aircraft. Once the initial conditions were satisfied and mutual aircraft visual sightings were confirmed, the engagement began with each aircraft free to maneuver to gain or maintain an

advantageous position. The free engagement was discontinued below 500 feet and/or when both crews lost sight of each other. The initial setups included:

1. Abeam flyover (bogey at hover)
2. Tail chase
3. Head-to-head
4. Side-by-side

A limited number of Stinger air-to-air missile (captive flight trainer) engagements were conducted to record launch platform (406 CS) maneuver data and missile lock-on capability for targets (AH-1S, AH-64A, and SA-365N-1) at various ranges, aspects (relative headings), and levels of evasive maneuvering aggressiveness, including non-jinking, defensive jinking, and free offensive jinking. Due to the classified nature of the data, the results are not discussed in this report.

The AACT IV team, consisting of those participant agencies given in Appendix B, completed 18 data flights. These flights consisted of 11 ACM flights, 3 air-to-air Stinger (ATAS) flights, and 4 single-aircraft performance and agility flights. Seven of the ACM flights involved off-axis or turreted "firing" from one or both of the combatants. While the total NATC on-site flight hours (including instrumentation and maintenance check flights, maneuver familiarization flights, and data flights) for all AACT IV aircraft amounted to nearly 87 hours, the total productive flight time for the 18 data flights was approximately 22 hours. Numerous additional flight hours were accumulated by each of the AACT IV aircraft during training, envelope expansion, and instrumentation check flights prior to arrival at the Patuxent River NATC. For example, a total of 212 flight hours was recorded for the SA-365N-1 during the AACT IV buildup, test, and post-test periods.

The number of agility maneuvers and free engagements flown by each aircraft during AACT IV is listed in Table 1. This table also shows the one-on-one aircraft combinations flown during these tests. As seen, the 406 CS did not fly ACM gun engagements against the AH-1S or the SA-365N-1 due to the early but necessary departure of the 406 CS from Patuxent River to meet other BHTI project commitments.

METHOD

The AACT IV engagements were flown under day visual conditions with each aircraft at a near common fraction (95%) of aircraft maximum gross weight. (Note: The AH-64A was flown at 92% maximum alternate gross weight and the SA-365N-1 was erroneously flown at 87% maximum gross weight early in the program. The SA-365N-1 was corrected via ballast to 95% maximum alternate gross weight for the majority of the data flights.) Each one-on-one flight commenced with a period of prebriefed warm-up maneuvers. All of the "gun" engagements were initiated at separation ranges of 1500 feet or less and conducted between the altitudes of 500 and 2000 feet. A minimum

separation distance between aircraft for all engagements was nominally 500 feet; however, when the NATC radar computed closure rates were not excessive (in the opinion of an observer safety pilot stationed in the test range radar facility), a separation distance of 250 feet was permitted before a "knock it off" was issued for the engagement. An advisory call of "bubble" was given at 500 feet when this condition existed. The "missile" engagements were generally initiated at much greater stand-off ranges (greater than 1500 meters) and thus generated much smaller crossing rates than those for the "gun" engagements. The AACT IV Rules of Engagement (ROE) (Appendix C), as briefed and followed during the test, are consistent with those followed by the Army in ACM training, as evolved from the MAWTS-1 syllabus. Flight restrictions and operating limitations were established by the Operator's Manuals,[4-7] airworthiness releases, and the approved Flight Test Plan.[3] Summaries of the safety precautions and operating limitations for the AH-1S, the AH-64A, the SA-365N-1, and the 406 CS are given in Appendixes D, E, F, and G, respectively.

Certain gun engagement assumptions and limitations were imposed upon the AACT due to (1) limited capabilities of test facilities and equipment, (2) the evolutionary nature of the tests, and (3) safety-of-flight considerations. The primary engagement conditions and safety precautions were:

1. Prior to each ACM flight, all participants were briefed on the test card engagement initial conditions. The ROE in Appendix C were included as part of each briefing.

2. Air-to-air combat at ranges less than 1500m (i.e., gun range) was conducted based on the premise that gunnery encounters demand more of the aircraft's maneuvering performance than missile engagements at longer ranges.

3. Only one-on-one helicopter engagements were conducted.

4. Qualified observers were positioned in the NATC air traffic control tower to visually monitor the test for safety and ACM critique and in the telemetry data stations to monitor real-time critical aircraft parameters for safety of flight.

5. ACM engagements were employed via LWSs with straight-line ballistics and laser reflectors (mounted on target aircraft) for hit/miss error measurements.

6. Unsophisticated optical aiming methods were employed for fixed gun engagements (exception: SA-365N-1 equipped with HUD).

7. Both one-on-one aircraft were required to have visual sighting of each other before an engagement could begin.

8. Each engagement continued until either the learning objectives were met (i.e., there was no "kill" on first pass) or a "knock it off" was called due to safety or other constraints detected by any of the test personnel.

9. ACM flights were conducted only during day visual meteorological conditions. No air defense threat was imposed and no terrain masking was permitted.

10. A 500-foot minimum or "hard deck" recovery altitude above the ground was observed (a radar tracking, telemetry, and safety constraint) as well as a 1500-foot nominal (2000 foot maximum) recommended climb altitude ceiling.

11. Test aircraft were to maintain a separation safety "bubble" of at least 500 feet during free engagements (200 feet during tail chase maneuvers).

Several data recording systems were employed in AACT IV. Those systems included both aircraft onboard and ground-based data recording capability for magnetic tape and video. The data network shown in Figure 10 was developed and employed for the air combat tests. Two of the aircraft onboard data systems were designed and installed by AATD (AH-1S and SA-365N-1) while the other two aircraft systems were prepared and installed by BHTI (406 CS) and MDHC (AH-64A). Aircraft position data was recorded by the radar-tracking system at the Chesapeake Test Range (CTR) of the NATC. A real-time display at CTR provided information concerning X-Y-Z relative aircraft positions, velocities, headings, relative bearings, slant ranges (distance between aircraft), and closure rates. This data was then used to verify that the airborne aircraft had arrived at the test card initial conditions and to ensure that the separation safety "bubble" of each aircraft was not violated. Pertinent aircraft state and structural loads parameters were also received via telemetry and recorded by the Real-Time Telemetry Processing Station (RTPS). These data were used to monitor the designated safety-of-flight parameters noted in Reference 3. A "knock it off" call was immediately issued when the maximum (or minimum) approved excursions for any one of these parameters were exceeded. An aircraft crew member not flying during a given flight served as a ground safety observer stationed in the NATC airfield control tower. The parameters recorded on each aircraft can be found in the respective aircraft onboard instrumentation lists contained in Reference 3. Both the CTR radar and aircraft telemetry data were merged and stored on magnetic tape. The data was then converted to a format compatible with the Data Management and Analysis Package (DATAMAP).[9] The recorded DATAMAP formatted parameters are given in Appendix H for the AH-1S, AH-64A, SA-365N-1, and 406 CS aircraft one-on-one AACT IV pairings.

Structural data was recorded on the AH-1S, AH-64A, and 406 CS. Separate reports with regard to the component fatigue life implications and load exceedances of the 406 CS and AH-64A were written by BHTI and by MDHC, respectively.[10, 11] LWSs were used on

all four aircraft to collect "gun firing" data (both fixed forward and turreted), which includes hit/miss ballistic error data and line-of-sight (LOS) aiming errors. These data were intended to provide a measure of effectiveness (MOE) of the air vehicles in air-to-air combat.

DISCUSSION OF TEST RESULTS

GENERAL

The AACT program provided the first comprehensive engineering data base for helicopter air-to-air combat encounters. Helicopter maneuverability, agility, performance, handling qualities, and structural loads data were obtained during controlled one-on-one helicopter air-to-air combat maneuvering tests. The AACT data base consists of results from four test exercises (AACT I, II, III, and IV) including nine different air vehicles. Support to the program was provided by 19 Government and contractor organizations. A total of 53.5 flight data hours was recorded containing 1079 ACM engagements. The specific AACT IV matrix and aircraft configurations flown are presented in Table 2. Table 3 gives the sequence of flight configurations tested during the AACT IV exercise. The extensive test configuration matrix provided data for both fixed and turreted gun firing opportunities, air-to-air missile launch platform maneuver requirements, and single aircraft maximum performance capabilities.

Throughout the AACT phases, three basic types of maneuver scenarios were performed by the participating helicopters: single aircraft agility maneuvers, dual aircraft structured engagements (as per FM 1-107), and dual aircraft free engagements. A limited number of Stinger air-to-air missile (captive flight trainer) engagements were also conducted during AACT IV. The majority of the flights were flown at a near common fraction of aircraft maximum gross weight as depicted in Table 4.

The AACT IV program also provided an opportunity to further refine the previously developed flight test techniques used to evaluate helicopter-vs-helicopter combat potential while using U.S. Army ACM tactics. The purpose of the engagements for AACT IV, as with the previous tests in the AACT series, did not include tactics development or the performance ranking of helicopters. The testing of several helicopters via the AACT methodology provided an extensive, as well as consistent, data base that permitted the formulation of general conclusions based on quantitative results of attributes, capabilities, and shortcomings of rotorcraft in the air combat maneuvering environment. While each participant test vehicle often displayed unique advantages and disadvantages in the close-in air-to-air environment, the primary responsibility of the AACT analysis was to present the more synergistic results for discussion.

In general, to be most effective the helicopter must be point-designed for air-to-air combat maneuvering. Such a vehicle must have advantages in speed (to dash to or away from the battle position), maneuverability (for the close-in fight), agility (for agile ingress/egress and nimble response to avoid threat point fire weapons and to bring own weapons to bear), acceleration/deceleration (to improve combat effectiveness and decrease susceptibility), and durability (to withstand airframe and dynamic component ACM fatigue damage).

Due to the complexity of the ACM test and its highly dynamic nature, a variety of parameters can influence the results of any of the maneuvers or engagements. The data analysis reported herein was done on a collective basis, taking into account several engagements at a time. In this manner, the general trends are analyzed instead of a single data point that may or may not be representative of overall airframe performance.

Analysis of the AACT data indicated the following points:

1. Air-to-air maneuvers may have a significant impact on component replacement times and structural design criteria for helicopters employed in air-to-air combat.

2. Minimum time to turn through a given heading change, larger power margins to sustain a 3g turn at sea level standard conditions at best endurance speed, unlimited static sideslip capability, and a roll response of at least 75 degrees per second are requirements for an effective air-to-air helicopter.

3. The ability to accelerate and decelerate at near-constant body attitudes with fixed-wing fighter-type field of view (FOV) is an important attribute.

4. Automatic flight envelope limit cueing is essential in order for the pilot to maintain eyes out of the cockpit during engagements.

5. Off-axis (turret) gunnery provides added firing opportunities but does not mitigate the need for a highly maneuverable and agile aircraft.

In addition to this report, an unnarrated videotape documentary of the AACT IV buildup (primarily at Fort Eustis and Patuxent River) and sequences of air-to-air engagements is available through request to AATD.

TEST METHODOLOGY

The test methodology was formulated to address the problem of how to document aircraft agility/maneuverability/weapon capabilities involved in air combat maneuvering so that desirable aircraft characteristics could be identified and conclusions drawn concerning current state-of-the-art helicopters.

To compare the performance of dissimilar aircraft in a one-on-one simulated combat engagement, the one element that has been reinforced throughout the air-to-air combat testing is that the conditions must be strictly controlled if the data is to be both meaningful and consistent. To take advantage of the radar tracking capability of the CTR and the computer and data down-link capability of the RTPS at the NATC permitted the necessary test monitoring and control. The initial flight conditions were specified so that the relative azimuths, ranges, and airspeeds could be varied to develop scenarios for

realistic one-on-one air-to-air engagements (Figures 11 through 14). For the most part, the initial conditions of the AACT engagement were indicative of close-in fights within gun or cannon range, although a few flights were dedicated to air-to-air missile scenarios. The flight cards were modified for each AACT engagement to permit exploration and documentation of specific initiatives or aircraft features; however, the primary initial engagement conditions, that is, situations providing tactical advantageous, neutral, and disadvantageous positions to each aircraft, were maintained and recorded throughout the AACT series. A myriad of performance and structural data was recorded with selected instrumented parameters down-linked to RTPS for real-time monitoring for safety and data channel functionality. CTR tracking also monitored the engagements and provided aircraft separation advisory calls for flight card data point initiation and safety.

The air-to-air combat flight test methodology, as with any comprehensive test methodology, has its strengths and weaknesses. Some of the engagement conditions and precautions imposed on the test could give rise to challenges concerning the "realism" of the exercise. For instance, the "no kill on first pass" assumption is admittedly artificial given that depending on the detection range, an initial "live" encounter could be quite lethal and may include air-to-air missile, flechette rockets, and/or cannon firing down to point blank range. The "no kill" assumption is necessary, however, in order to maximize the data gathering and to induce the stringent air combat maneuvering encounters (in terms of performance and structural loads) that were sought. Also, the air-to-air maneuvering was confined in the vertical between 500 and 2000 feet above ground level (AGL), in order to maintain radar tracking for space position data. The V-n envelopes recorded in the test tend to deemphasize the low "g" envelope (i.e., less than 1g) since pitch-over for terrain masking was not permitted and thus was not a factor. Gaining the "perch" or altitude advantage was the primary maneuver tactic employed given the AACT constraints on the vertical maneuver dimension (i.e., 500 feet "hard deck" with no terrain masking).

Prior to the "free" ACM engagements, practice or familiarization flights for each aircraft pairing, as per Table 2, were conducted at an auxiliary airfield under the control of the NATC. Although flight test cards were prepared and briefed, the closure rates and ranges for these flights were not radar monitored for a safety "bubble." Due to the absence of this safety feature and the differing levels of AACT IV pilot experience in close-in ACM, this phase was perhaps the most hazardous portion of the test program. As mentioned previously, the low power, eye-safe LWSs carried by each AACT aircraft were off-the-shelf devices partially adapted for helicopter airborne use. The lasers demonstrated great utility in generating line-of-boresight aiming error data, but did not perform adequately in the full ballistic simulation mode. The deficiencies were in terms of ballistic drop and kinematic lead compensation for vehicle and turret rates and accelerations, and wind effects.

Several other comments are worth noting relative to the general conduct of the AACT IV exercise. The buildup/training flights proved to be extremely beneficial; flight crew

proficiency was visibly improved. Although the facilities at Naval Air Station (NAS) Patuxent River were excellent, and as guests of the NATC, the AACT IV team was accorded most requests, the necessity to use the main airfield for radar tracking and the limited test periods (requiring cessation of normal NAS flight operations) had a detrimental effect on the timely conduct of the test. The aircraft minimum separation monitoring task was complicated by the delay time involved in computing and presenting the slant range (distance between the one-on-one aircraft) to the CTR controllers. Further, the use of a minimum separation range of 500 feet was generally regarded by the pilots to be too restrictive for an air-to-air combat test.

The flight card data points were designed to be indicative of realistic, close-in fight initial conditions in order to induce the use of the best traits of the participating aircraft and to provide the safest possible encounters. The setups included head-to-head, side-by-side, tail chase, and abeam attacks against a hovering opponent (see Appendix I). The flight numbers of Table 3 and the flight event numbers in Appendix I assist with the interpretation of the unique flight engagement nomenclature shown in Appendix J. As outlined in Appendix J, the engagement numbers were developed for data management purposes and occasionally appear in the data figures discussed herein.

While the LWS hit/miss data is valuable for post-flight analysis, a real-time hit feedback system such as a flashing aiming reticle would permit the pilot to assess the actual effort required to put hits on target. Conversely, a means of warning the pilot of the target aircraft that it is receiving hits would undoubtedly add more realism to the engagements, as well as complexity to the airborne systems, but would likely result in a more valid profile of maneuvers required to avoid being hit or to at least reduce the hit susceptibility. This requirement would also necessitate a more accurate and realistic airborne ballistic simulation by the LWS.

As an adjunct to the AACT gunnery testing, a captive flight version of the Stinger missile with a fully active seeker head was qualitatively evaluated onboard the 406 CS for air-to-air combat use. The 406 CS maneuvering and performance time-histories were recorded, as were those of the target aircraft, for a quantitative definition of missile launch platform excursions and thus missile launch envelope requirements for short, medium, and long range air-to-air encounters. The results of this exercise are not discussed further in this report due to the classified nature of Stinger-related data.

AIRCRAFT PERFORMANCE ISSUES

It is clear that M&A are functions of many air vehicle physical parameters and characteristics. From an aircraft systems viewpoint, both the maneuverability and the agility of the airframe may be characterized by distinct, inherent influencing elements and overall measures of performance. Inherent influencing elements of maneuverability include power margin, maximum thrust (load factor), and structural constraints. The overall measures of this maneuverability suggest examination of envelopes, climb/descent

rates, turn rates, and acceleration/deceleration. The complementary inherent agility influencing elements include engine response, control power, controls and system integration, and handling qualities. The more subtle associated agility attributes or measures may be represented via accuracy of maneuvering, time to change maneuver state, and pilot workload. In short, maneuverability is "how much" and agility is "how quickly." The AACT data base essentially represents a composite of all these M&A measures in a real-world application.

To provide a further basis for continuing comparison and analysis of the attributes of the rotorcraft involved in the AACT IV, Tables 5 and 6 contain selected physical characteristics and derived parameters. The physical characteristics of Table 5 were used to calculate the derived parameters of Table 6, using the equations of Appendix K. The contribution or sensitivity of individual design parameters, such as found in Table 5, and the level of "goodness" of that parameter as it contributes to overall vehicle M&A attributes are often difficult, at best, to assess given the genuinely synergistic situation of AACT IV involving several distinctly different rotorcraft in free-engagement, one-on-one flight test scenarios.

At this level of analysis of the basic flight test data, the approach taken toward presentation of results was to define a requirement of capability for a vehicle designed for ACM rather than attempt to quantify specific physical characteristics that might comprise such a vehicle. Although beyond the scope of analysis undertaken herein, a systematic maneuverability/survivability trade-off analysis and preliminary design would most logically follow from the required aircraft capability (speed, rate of climb, turn rate, etc.), then continue with definition of the normalizing or "fundamental" design parameters (thrust to weight, power margin, power to weight, etc.), and finally conclude with detail design of the rotorcraft key physical parameters (hinge offset, disk loading, installed power, gross weight, etc.).

Handling Qualities

Directional Control. In the highly transient environment of one-on-one air combat maneuvering, the SA-365N-1 as equipped with the standard shrouded 11-blade fan-in-fin Fenestron antitorque system exhibited, through aggressive yaw rate and sideslip excursions, distinctly positive ACM attributes in terms of aircraft yaw axis agility and robustness. While the maneuvering of the SA-365N-1 helicopter during AACT IV was generally very aggressive in all axes, the directional control axis was exercised by the pilots without apparent concern for the potential of inducing an "over" condition (that is, overtorque or overstress). As shown in Figure 15, unlike the other three AACT aircraft, full pedal authority on the SA-365N-1 was explored throughout the speed envelope. (The "scatter" plot shown in Figure 15 indicates a composite of data points for pedal position with airspeed at 0.2-sec intervals for several air-to-air engagements.) The only evidence of any sustained damage to the directional control device was the required replacement, on two occasions, of all the plastic bushings for the Fenestron

blade pitch bearings due to cracking and partial fragmenting. Total failure of a bearing antifriction ring would have resulted in damage to the blade root bearing surface and housing assembly, but no immediate danger of slinging a blade existed. No damage to any other directional control drive train component was noted.

The full left or right pedal travel in conventional helicopters can cause overtorque of the engine, structural damage, or tail rotor stall, resulting in loss of antitorque control. As evident from Figure 16, the AH-64A and BHTI 406 CS as well as the SA-365N-1 generated moderately high yaw rates trying to point the aircraft, and thus the gun in the fixed gun mode, at the bogey aircraft. Not unexpectedly, the AH-64A and AH-1S turreted configurations exhibit slightly milder yaw rate extremes due to the dexterity of the turret. The azimuth and elevation LOS angles to the bogey scatter plots (Figures 17 and 18) reflect the difference between the aircraft "positioning" task for the turreted configurations and the aircraft "pointing" task for the fixed gun configurations. For the fixed gun configurations there are generally three sets of clustered points in the 360-degree LOS plots of Figure 17. The clusters at $\pm$180 degrees occur when the bogey is at the "6 o'clock" or directly aft position. The clusters at about +100 degrees indicate the frequent turning maneuvers executed in an attempt to get or keep the bogey in the forward hemisphere of the FOV. The clusters on either side of zero degrees azimuth represent the desired nose-at-bogey position acquired by turning or sideslipping the aircraft to complete the pointing task. Not surprisingly, even the turreted configurations shown in the Figure 18 turret window LOS plots tend to align or point the aircraft at the bogey whenever possible to keep the bogey in the forward hemisphere of the FOV for tactical reasons. However, the scarceness of LOS points at or near the zero degree position may suggest an FOV problem for the pilot's helmet directed sight in the directly forward azimuth that was compensated for by tracking the bogey with the nose of the aircraft slightly left or right of nose-on. (Pilot debriefing commentary did not, however, identify this particular situation.)

As was concluded from the HAC III studies,[12] pilots tend to engage nearly on-axis, regardless of gun azimuth capability. These results are somewhat replicated by the AACT turreted gun engagements as depicted in Figure 18. Near on-axis firing positions apparently preserve tactical initiative from an offensive as well as defensive perspective. Additionally, gun accuracy is increased as gun azimuth is decreased. Variations in muzzle velocity, together with any fire control ballistic equation induced error, are the primary contributors to ballistic dispersions. Figure 19 illustrates 6-degree-of-freedom (DOF) simulation results comparing dispersion errors when the aircraft is at a cruise speed of 164 knots. A muzzle velocity error propagates into an azimuth error for side firing but does not affect azimuth error for forward firing at the ranges encountered in the AACT engagements.

Since the SA-365N-1 and the 406 CS were not equipped with a functioning gun turret (only fixed gun), uncoordinated turns were used extensively by the crews to assist in maneuvering their helicopters to attain a firing opportunity. Use of directional control

only to bring the aircraft weapon to bear on an adversary by pivoting the aircraft was made during virtually every engagement. The ability to point the nose of the helicopter without regard to sideslip limits, as demonstrated by the SA-365N-1, permits a much greater degree of air-to-air vehicle flexibility, particularly for the fixed gun rotorcraft. Figure 20 shows a series of the excursions of the sideslip conditions incurred by the AACT IV aircraft. Each aircraft approached or exceeded the published sideslip envelopes. The SA-365N-1 demonstrated large sideslip excursions at speeds in excess of 130 knots. The unfortunate truncation of the AH-64A sideslip data does not permit a similar examination. (Note: The truncation of the AH-64A and AH-1S sideslip envelopes is due to an artificial boundary imposed on the data channels and not a phenomenon of the aircraft.) The quality of a shot opportunity in terms of the probability of hit or kill of an adversary from a large sideslip firing condition would, admittedly, be marginal. However, this maneuver flexibility will help acquire the tactical advantage.

The same sideslip capability could also serve well defensively as a means of at least minimizing an adversary's tracking effectiveness or P_h by exposing the minimum presented area (i.e., frontal view) to the adversary aircraft, as per the fixed gun configurations of Figure 17. Also, by presenting a changing aircraft longitudinal axis attitude that is significantly different from the aircraft flight path, a further evasive tactic is available to disguise or mask (to some extent) the anticipated track of the aircraft as perceived by the adversary. The skillful use of sideslip for weapon pointing and evasive maneuvering thus provides a distinct tactical advantage. As Figure 21 from Reference 13 demonstrates, yaw maneuvers at higher speeds have additional benefits in reducing turn times through quicker decelerations. Note that use of 24 degrees of sideslip reduced the baseline helicopter turn time by nearly 20%. The SA-365N-1's sideslip envelope provided a capability that could further enhance this maneuver (Figure 20). Directional control flexibility at all airspeeds is a desirable characteristic in air-to-air aircraft.

<u>Aircraft State Conditions at Firing Opportunities</u>. Figures 22 and 23 show LOS to bogey, attitudes, rates, and load factors for two representative one-on-one ACM engagement pairings at a mutual advantage initial condition. The LOS figures also graph azimuth and elevation bands indicative of when a geometric firing opportunity was available for either aircraft during the engagement. While these bands seem somewhat generous (approximately ± 12 deg) for a fixed gun engagement, they represent a forward-looking region in which the bogey was tracked or through which it crossed. With the test pilot opinion that small control adjustments could often fine-tune the LOS and without any sophisticated fixed forward sighting system available or activated, these fixed gun firing opportunity regions may be rationalized for this type of analysis.

Important to the understanding of the ACM environment and in particular the gyrations that the aircraft must undergo in either arriving at and maintaining the firing opportunity or evading the adversary are the extremes (minimum and maximum) of key aircraft state parameters at or just before the critical firing opportunities.

Attitude control, particularly pitch attitude, during the air-to-air engagement is extremely important in terms of precision and magnitude. As soon as the nose comes down to accelerate or to recover from a large nose-up attitude, the vehicle loses its offensive posture due to its own rotor masking. The firing window elevation angle-of-sight (AOS) to bogey data for the turreted configurations shown in Figure 18 indicates the frequency at which the bogey is above the maximum up-elevation of the turret. Figures 24 and 25 (pitch attitude vs airspeed for the 365N-1 and AH-64A) typify the nose-down pitch attitude (20 to 30 deg) excursions experienced by helicopters accelerating from hover or low airspeed. Such accelerations mask even straight-ahead firing opportunities.

The sample time histories in Figures 22 and 23 reveal near-limit and above-limit excursions of the given variables. Although the AACT IV data base indicates that fixed gun configurations attain far fewer firing opportunities than turreted configurations, the fixed gun maneuvering excursions are generally more dynamic. The turret does not, however, mitigate the need for maneuver capability in terms of load factor and rates to arrive at an apparent advantageous fighting position. High rates are required to attain acceptable firing positions. Rates tend to settle for the turret configuration once the firing opportunity is attained, giving way to HMD or HMS tracking, particularly against a fixed gun adversary. Regardless of the gun configuration (fixed or turreted), the close-in gun battle necessitates that an ACM aircraft be very capable in power margin, dexterity, and structural integrity to repeatedly generate the rates, control the attitudes, and sustain the load factors to maintain an offensive posture. To run is likely to die!

Maneuverability

Turn Rate and Radius. Given the reality of all aspect missiles and the high probability of surprise gun encounters, instantaneous or transient turn rate, i.e., the ability to quickly and accurately point the nose of the aircraft at the target, is sometimes more important than the turn radius or even the sustained turn rate.

The data presented in Figures 26 through 28 was gleaned from single aircraft maneuvering performance flights during AACT IV for a return-to-target type maneuver. The transient turn rate was based on turn capability through 90 degrees while the sustained turn rate was derived from the measured rate as the aircraft continued through 180 degrees. Simple geometric measurements from X-Y space position plots yielded the turn radius values. (Note: The maneuver initial V_H values differed for each aircraft: AH-64A at 139 kt, 406 CS at 111 kt, SA-365N-1 at 158 kt, and AH-1S at 124 kt.)

Available transient turn superiority was demonstrated by the 406 CS with the exception of the very low speed to hover region (see Figure 26). Since pedals were used to increase turn rates, the trend reversal at low airspeed is believed to be due to the apparently weaker yaw control power of the 406 CS. However, the greater midrange speed to high speed turn rates are perhaps associated with the 406 main rotor's ability to generate pitch rate (as evidenced by pitch rate with bank angle which gives turn rate).

This capability is augmented by the relatively low body inertias of the 406 CS compared to the other AACT IV vehicles.

The steady turn rate data of Figure 27 indicates, not unexpectedly, that sustained turn capability is somewhat lower than transient with the notable exception of the SA-365N-1. Due to a yaw-rate stability and control augmentation system (SCAS) saturation situation in hover, the yaw rates of the SA-365N-1 are allowed to grow or wind-up extremely fast through 180 degrees of azimuth. The other vehicles are rate limited (via SCAS intervention) throughout the speed regime explored. The 406 CS hover point turn rate is noticeably lower than might be trended due to this SCAS rate limit.

Figure 28 presents turn radius as a function of airspeed. While the AH-64A and SA-365N-1 exhibit similar steady turn rates at V_{BE} and V_H, the AH-64A generates a larger turn radius. This is perhaps due to the higher body inertia which may cause the AH-64A to "slide" to the outside of the turn during the return-to-target maneuver. On the other hand, the AH-1S demonstrated consistently lower turn rates and thus larger turn radii; this was clearly a result of the 60-degree bank angle limitation and a reluctance to generate yaw rate and sideslip while banked which, with the teetering rotor, tends to aggravate main rotor flapping.

It is therefore reasonable to expect that a future vehicle with the potential for air-to-air encounters should possess close encounter turn capabilities equivalent, if not superior, to those of the existing technology vehicles discussed above. Since turn performance is governed by an aircraft's ability to generate and sustain load factor, then from basic turning flight performance relationships it would not be unrealistic to expect turning performance requirements of 50 degree/second transient and 40 degree/second steady at the best maneuvering speed (approximately 60 to 80 kt) which would require 3.5 g transient and 3.0 g steady for future ACM vehicles. At V_H speeds of 120 to 150 knots for such ACM vehicles, an engineering estimate of 40 degree/second transient and 30 degree/second steady yields requirements of 4.0 g transient and 3.5 g steady.

<u>Accelerations, Climbs, and Excess Power</u>. Brute power provides many side benefits in the rotary-wing flight spectrum. As applied to the ACM environment, power means linear acceleration, sustained G (turn rate), climb rate, and speed.

Longitudinal acceleration and maximum climb rate are a direct function of excess thrust (dependent upon excess power). In the tactical ACM situation, the ability to accelerate (and climb as necessary) is critical. Since with conventional rotorcraft, longitudinal acceleration is achieved by tilting the thrust vector or rotor tip path plane, the pitch attitude excursions that result are a definite detriment to pointing a weapon at a maneuvering target. Both transient (trading kinetic for potential energy) and steady climbs were used regularly in AACT IV to gain the "perch" or altitude advantage over the adversary. The assumption was that the immediate threat of an airborne adversary

outweighed that of a potential ground threat. Therefore, the rotorcraft used 3D versus only 2D maneuvering to evade or attack.

AACT IV employed two engagement setups or initial conditions that suggested or required the use of both acceleration and climb to neutralize a distinctly disadvantageous position. With one aircraft in a low hover condition (at the 500 foot "hard deck") and the other aircraft overflying the hovering vehicle, the fight was initiated. Typically, the response of the hovering aircraft was to turn, pitch-up, and take a quick shot. Following that, it was imperative that the hover aircraft climb and accelerate in an attempt to neutralize this purely defensive situation.

The acceleration and climb capabilities of the AACT IV aircraft were recorded during single ship performance flights using the Patuxent NATC space position radar facilities. Figures 29 and 30 show the time to accelerate in seconds and the acceleration capability in knots/second, respectively. Although the SA-365N-1 reaches the various speed gates earlier than the other vehicles shown, it was flying at this point at only 87% of its maximum alternate gross weight while the other vehicles were flying at between 92 and 95% of their respective maximum gross weights. At 110 knots the 406 CS is approaching its usable power limit. The acceleration capability represented in Figure 30 (taken from local slopes or rates of change at various airspeed points along the "time to accelerate" curve of Figure 29) seems somewhat disjointed but nevertheless indicates the power bucket speeds for these aircraft and the light gross weight of the SA-365N-1. At 80 knots the aircraft accelerations cluster at about 4 knots/second (6.5 kt/sec for the light SA-365N-1). The spread at 50 knots is representative of the pure excess power difference among the aircraft. The higher acceleration demonstrated by the 406 CS over that of the AH-1S at 50 knots is a result of the proximity of the 406 CS to its minimum power speed at 50 knots. At 90 knots the acceleration capabilities of the vehicles are fairly close at about 2 to 3 knots/second (and 4 kt/sec for the SA-365N-1). While the AH-64A has greater excess specific energy (P_s), its inertia/drag characteristics contributed to slow accelerations.

Acceleration and deceleration are essential in engagement and disengagement, as well as evasive, escape, escort, and intercept maneuvers. To succeed in aerial combat, one must be able to shoot first and more often. Attitude control during the engagement is extremely important because as the nose comes down to accelerate (as per Figures 24 and 25) or to recover from a large nose-up attitude, the vehicle becomes a target due to its own rotor masking. Further, extreme nose-high or nose-low maneuvers visually telegraph the pilot's intentions to his adversary, permitting evasive maneuvers. Therefore, to more effectively attain or maintain the combat initiative, velocity changes should be achieved without entering very high or low pitch attitudes.

Power versus weight and excess power have been critical items since the inception of aviation. Excess power is even more critical once engaged in the close-in air-to-air fight. Figure 31 shows the single ship climb performance initiated from the V_Y or minimum

power speed for each aircraft. Perhaps the only surprise here is the superior climb performance of the AH-64 even in view of the relatively lighter weight SA-365N-1. The brute excess power of the AH-64A (see Table 6, the lowest AACT power loading ratio of 5.74 but the highest disc loading of 8.97) is evident in Figure 31, as is the power or torque limit of the AH-1S. Figures 32 and 33, 3D flight path plots of the hover/overfly setup engagements for the AH-64 and SA-365N-1, show the importance of climb power to go vertical and get the "perch" or altitude advantage.

A projected rate of climb capability in the area of 4000 feet/minute at the speed for best climb would not be unrealistic for an ACM vehicle. The AH-64 achieved a climb rate of about 3,150 feet/minute at about 92% of its maximum alternate takeoff weight (16,222 lb). (Note: Climb performance from hover was not a factor in AACT IV other than in two one-on-one ACM initial conditions, nor was climb from hover specifically recorded in the single aircraft performance testing phase.)

A consequence of a healthy power margin (excess thrust) is good maneuverability, particularly in terms of linear acceleration and climb rate. The ACM environment puts demands on these attributes to engage and gain the "perch" advantage. A significant bonus in firing opportunities could be gained from acceleration/deceleration capability without large attitude changes - a feature not present with the conventional helicopters discussed herein.

<u>Maneuver Envelopes and Limits</u>. The AACT data base provides a unique and sufficiently broad collection of rotorcraft performance and maneuverability data from which to define ACM composite flight envelopes based on actual excursions of vehicle in-flight parameters. Specific ACM attitude, rate, acceleration, and power train envelope utilizations may be gleaned from the data base. Those envelopes are, of course, defined within the context of the specific rotorcraft participating in the test. The analysis, therefore, is based on both the absolute values of the key parameter excursions and the breadth and position of these ACM excursions relative to the particular vehicle design envelope boundaries. From an assessment of these types of presentations and with knowledge of the specific adversary and onboard weaponization configurations of ownship and bogey, an educated projection of those flight envelope attributes required for an ACM derivative rotorcraft is possible.

From the AACT data base, histograms were constructed for the parameters of airspeed, attitudes (pitch and roll), rates (pitch, roll, and yaw), engine torque, and load factor. These histograms, Figures 34 through 41, represent the highest excursions of these parameters for each of the AACT IV aircraft as well as reveal that portion of the total "fights-on" engagement time spent by each rotorcraft configuration (i.e., fixed and turreted gun) at the various levels of these parameter excursions. These histograms, plus those contained in Reference 14, provide an excellent summary of the activity of the above key parameters.

The true airspeed histograms in Figure 34 indicate, albeit not surprisingly, that the highest percentage of engagement time is spent at speeds for minimum power or best maneuvering speed regardless of the vehicle or gun configuration. For the AH-64A and SA-365N-1 in fixed gun mode, the slightly higher percentage of time spent in the 125 to 150 knot range is a product of the flight test card initial conditions where entry speeds of 130 knots were typical. The speed histogram excursions for the AH-64A and AH-1S in both fixed and turreted configurations were, for the most part, quite similar. The AH-64 and SA-365N-1 also exercised their inherently larger excess power capability over a larger speed range, demonstrating the distinct advantage of a broad power bucket, greater power margin, and transient torque capability beyond 100%. Although excess power means greater speed capability, the utility of this capability is lost or seriously compromised in the close-in gun engagement as portrayed in AACT IV since neither terrain masking nor stand-off target acquisition were test-scenario features available to the combatants. Given this scenario, two possible conclusions can be drawn: (1) high speed is not important since high turn rates and high climb rates are associated with low speeds, and (2) the aircraft with the most excess power is going to "win".

Under more realistic conditions of a ground-to-air threat, however, these conclusions can be misleading. Excess speed is nevertheless desirable since it enhances pilot battle options. Speed affords the attacker the capability to maneuver for advantageous attack positions, minimizes exposure to ground fire (acknowledging a point of diminishing return since greater speed usually requires greater altitude above masking terrain features), and offers an avenue of escape (from chance encounter gun engagements primarily) if the shooter fails to destroy the target or chooses not to fight. Modern weapons capabilities are sufficiently lethal, however, to preclude a turn-and-run maneuver in most cases. For rotorcraft, the maxim "speed is life" is applicable up to a point. In the current threat environment, helicopter survivability increasingly relies on terrain flight. A dash speed for a rotary-wing air-to-air aircraft of 200+ knots would not be unrealistic. Although certainly terrain-dependent, contour flight is difficult, at best, above 200 knots, necessitating a robust "g" and "g-rate" capability in order to avoid obstacles. Unless airspeeds of 500 knots are attainable, the ability to outrun air defenses is greatly diminished. However, as suggested by Reference 15, contour flight up to approximately 200 knots is feasible and thus permits reduced LOS tracking time for adversary ground-based missiles. Speed can therefore be considered a valuable element in the total ASE package.

The pitch and roll attitude histograms are given in Figures 35 and 36. In general, the capability required of a rotorcraft in ACM is whatever altitude and angle of pitch, bank, or yaw is necessary to maneuver to the spatial position from which to direct the fight. For fixed gun configurations, this requires pointing the aircraft and thus the gun. For the turreted gun configurations, this involves aircraft positioning to maximize the exposure of the bogey in the turret "window" (which minimizes "hitting the stop" occurrences), as well as to maximize the quality of the shot (i.e., the probability of hit) by reducing large off-axis shot angles. Based on the pitch and roll attitude extremes

attained, the presence of a turret does not appear to mitigate the need to maneuver the aircraft either defensively or offensively. Roll or bank angle capability beyond the typical training limits of 60 degrees must be permitted. ACM requirements of roll attitudes between 90 to 120 degrees would not be unrealistic, nor would pitch attitudes approaching +90 degrees.

Pitch and roll rate histograms are shown in Figures 37 and 38; yaw rate histograms were shown in Figure 16. The maneuverability of the aircraft depends on the rates that can be commanded to generate a heading or attitude change, and the associated agility is evidenced by the time and precision needed to achieve given changes. The figures show that the rate extremes seen by both turreted and fixed gun configurations were similar, while a greater time at the milder corresponding rates was experienced by the turreted vehicles. The higher rates are necessary to initially position the aircraft for turret window "firing" opportunities; once there, the bogey can be tracked with the turret rather than with the nose of the aircraft. The fixed gun configurations required use of the higher airframe rates more often to point the nose of the aircraft and thus the gun. This fact is particularly evident in yaw as a great deal of yaw rate activity is shown in Figure 16 throughout the available yaw rate envelopes (as defined by the sideslip envelopes in Reference 3). Although the largest percentage of ACM time was spent at pitch, roll, and yaw rates of +10 degrees/second, an ACM rotorcraft (based on a projection of the demonstrated data) should have the capability to generate controllable angular rates as high as 75 degrees/second in roll, 50 degrees/second in pitch (nose up), and 60 degrees/second in yaw. The roll and yaw capability should be available at all speeds (particularly with fixed guns), while the pitch rate capability is necessary at or below typical minimum power airspeeds. Aggressive jinking, roll reversals, pull-ups/pushovers, etc., are rate dependent maneuvers required for effective ACM.

Figure 39 contains the engine torque histograms. The capability to approach and, if necessary, exceed the 100% of maximum continuous torque limit without damage to the drive train is a distinct advantage in the ACM environment. The engine torque transient capability of the AH-64A and SA-365N-1 was exercised repeatedly. On the other hand, the AH-1S helicopter is limited in roll agility by its propensity for drive train transient overtorques. Left roll rates in the AH-1S produce increases in torque at a rate that demands considerable pilot attention and thus high workload. Freedom from any adverse effects of transient maneuverability over-conditions is essential to give the pilot the confidence needed to command the abrupt offensive and defensive jinking rates required in air combat maneuvering. The critical power train parameters should be self-limiting or protected from pilot abuse. The vehicle should be sufficiently robust to permit transient overtorques without catastrophic consequences.

The load factor histograms are given in Figure 40. Although from this data (plus the minimum/maximum load factor graphs in Reference 14 for six additional AACT vehicles) it can be seen that the majority of the engagement maneuvering time is spent at load factors (N_Z) between 1.0 and 1.5 G's, an ACM rotorcraft must be capable of much more.

N_Z levels as high as 3.0 G's and as low as 0.5 G were attained in repeated situations for both the AACT IV fixed and turreted gun configurations (with the exception of the AH-1S). The high load factors, with recorded transient values of over 3.0 G's, translate into turn rate and thus heading change for either offensive gun pointing or defensive evading. However, once in the "saddle" or firing position, N_Z levels required are lessened. Since N_Z capability is also related to power and power loading, at least up to the rotor's maximum ability to produce thrust just below stall, the lower power loadings (GW/HP) of the AH-64A and SA-365N-1 from AACT IV and the S-76 and UH-60A from AACT II[14] contributed to the higher load factor levels demonstrated by these aircraft. Rotorcraft developed for ACM should be capable of transient (3 seconds) and steady-state (greater than 3 seconds) load factors not less than those shown in Figure 41. Furthermore, these load factors should not induce unacceptable torque or rotor speed excursions.

A main rotor flapping histogram for the AH-1S is given in Figure 42 and portrays data from both AACT III and AACT IV. The AACT IV AH-1S was equipped with the standard 540 rotor blades and a flapping restraint device or hub spring, while the AACT III AH-1S was flown with the K747 blades and no hub spring. Both aircraft were flown at nearly the same gross weight and were piloted by the same experienced test pilot. The hub spring on the AACT IV AH-1S was designed to engage at just over 30% of maximum main rotor flapping (i.e., 12.5 deg = 100%). In the region of flapping excursions for which the hub spring was active, the aircraft with the hub spring demonstrated generally less ACM engagement time at these slightly higher flapping levels. Flapping excursions for the AH-1S with the hub spring were generally less extreme than without the device. It should be noted, however, that the hub spring was employed on the AACT IV AH-1S to provide a mast bumping safety margin rather than to enhance its maneuverability.

Figure 43 presents the data excursion envelope plots of load factor (V-n) for each one-on-one ACM flight (i.e., each aircraft ACM pairing). The envelope plots of sideslip (V-β) were given in Figure 20. The approved AACT IV safety-of-flight envelope boundaries are also shown on the flight test envelope data plots to indicate where within (or outside) the approved design envelope boundaries the various aircraft were operated. The V-n and V-β plots reveal how heavily the aircraft were taxed and how uncoordinated the ACM flight environment can be. For the sideslip envelopes (V-β), it is apparent that the data excursions for the AH-64A and AH-1S were artificially truncated (except for a few spurious data spikes) due to a data channel calibration setup error. Aggressive aircraft sideslip and yaw utilization during air combat maneuvering may upset or degrade the onboard fire control solution. Maneuver combinations involving sideslip and climb have caused structural problems during testing (as per AUH-76 (AACT II) tail rotor spar fatigue damage, SA-365N-1 Fenestron blade pitch bushing deterioration, and AH-64A tail rotor gearbox quill shaft static limit exceedance).

Main rotor speed versus load factor (vertical) and engine torque versus airspeed (AH-1S only) data excursion plots shown in Figures 44 and 45 indicate the main rotor and engine dynamic characteristics.

The air-to-air rotorcraft should therefore be capable of withstanding transients in rotor speed, torque, load factor, etc., in order to obtain the edge in an ACM conflict. The directional control axis is of particular importance in this highly uncoordinated environment. Based on the flight envelopes demonstrated, full pedal inputs at any flight condition should not induce any structural or control problem and transient (5 to 10 seconds) sideslip capability should approach those limits shown in Figure 46. The uncoordinated flight regime, including sideslip and angle of attack, will undoubtedly complicate the accuracy of weapon fire solutions (fixed or turreted). This type of flying puts an extra burden on the vehicle weapons suite, requiring "smart" sights and weapons to deliver ordnance on target from an uncoordinated platform. If coordinated flight must first be reestablished, then some portion of the advantage of a nimble, robust air vehicle is lost. In all likelihood, the rotorcraft involved in helicopter versus helicopter air combat maneuvering that can point first and shoot accurately wins.

Rotorcraft agility and maneuverability can therefore be summarized in terms of high G turns; highly controlled roll, pitch, and yaw rates; and excess power for vertical and horizontal flight. Survivability in the rotorcraft combat environment cannot depend solely on a "flying tank" design philosophy, for no amount of hardening will assure survival. Improved survivability must be realized through other basic tenets: communication of intelligence, target acquisition, fire control, and airframe performance.

Dynamics

ACM Structural Loads. Separate contractor technical reports address the fatigue analysis results derived from the ACM testing for two of the four AACT IV aircraft. MDHC prepared a technical report presenting the implications of ACM on key component fatigue lives and static loads for the AH-64A.[11] A similar contractual analysis effort and report were completed by BHTI for the 406 CS (as it relates to the OH-58D).[10]

From Reference 11, the AH-64A loads recorded from the air combat maneuvering were determined to be much higher for several components than loads from the design maneuver spectrum. Similar results were identified for the UH-60A and AUH-76 from AACT II based on a Sikorsky Aircraft ACM loads analysis.[13] Several key components suffered significant reductions in component replacement times due to the ACM fatigue life damage. The particular maneuvers or engagements that yielded the highest damage fraction for four AH-64 ACM sensitive components were examined for concurrent values of key flight envelope parameters. The particular engagements annotated by the high damage fraction were also noted by the test engineer as requiring structural "advisory calls" and "knock it offs" from the ground station due to safety-of-flight monitoring exceedances. There were no overt indications to the pilot of such exceedances.

The pertinent structural traces from the MDHC report are shown in Figures 47 through 50 for the tail rotor fork torque, tail rotor gearbox quill shaft torque, tail boom skin torsion, and tail boom stringer bending (vertical). For the tail rotor components, the

higher fatigue damage was due to the transient severity of the maneuvering, while for the tail boom the increase in the damage was due to the longevity of the engagements containing aggressive compound maneuvers. The coincident excursions of airspeed, load factor, and sideslip during the structural exceedance (fatigue damage) time periods are shown on V-n and V-β envelope plots for the AH-64A (Figures 51 and 52). These plots indicate that structural safety "knock it offs" can be encountered while operating within the recognized flight envelope. It should be noted, however, that artificial truncation of the AH-64A sideslip data prevents us from knowing how far out of trim the aircraft became. It appears that the AH-64A may have exceeded the established sideslip limits in this maneuver. In any event, of further significance is that the pilot had no overt indication that a structural endurance limit was approached or exceeded.

The time history plots for key aircraft state and flight control parameters during the structural exceedance period for each of the components, noted previously in Figures 47 through 50, are shown in Figures 53 through 56. (Note: The time history records shown in Figures 53 through 55 commence 25, 47, and 7 seconds, respectively, earlier than those traces shown from MDHC records in Figures 47 through 49; the records in Figure 56 commence 15 seconds later than the MDHC record in Figure 50.) For this program the maneuver severity was denoted by peak maneuver loads and by duration of oscillatory loads above the 1-hour level. Maneuver oscillatory loads in excess of the 1-hour level were limited to 10 seconds duration per condition.

Current aircraft structural envelopes are less than adequate for air-to-air maneuvering. High loads in both the airframe and the dynamic components can unknowingly be reached without any abnormal vibrations or cockpit indications being present. Even with an experienced, knowledgeable crew performing relatively benign maneuvers, static limits of components can be reached and exceeded. The AH-64A, for instance, encountered 106% of limit load on the tail rotor gearbox quill shaft during a particular ACM reversal maneuver (Figure 48). The pilot had no indication that a structural limit was exceeded. Fortunately, the limit margin of safety for that component is 20%. Aggressive reversal rates which generate high flapping and structural loads are frequently required in the ACM environment.

Reference 11 also compares the fatigue damage for fixed versus turreted gun engagements. The results of the life calculations for 21 fatigue sensitive locations of the AH-64 indicate that the fatigue damages for the fixed gun engagements were nearly always greater than for the turreted gun engagements. The location that showed the largest difference between the two gun modes was the tail rotor controls bracket. The fixed gun mode results in an average life that is 83% of the turreted gun mode life considering all 21 locations.

This discussion of AH-64A exceedances must, however, be tempered by the fact that only the AH-64A data was analyzed (at this writing) in sufficient depth to make this brief presentation. Only the AH-1S rivaled the AH-64A in breadth of structural

instrumentation. Safety-of-flight "advisory calls" were made from the RTPS ground station for each of the AACT IV aircraft during the course of the test flights for such limit exceedances as main rotor and tail rotor flapping, load factor, and engine torque.

AH-1S Overtorque. Transient torque, evident in all single main rotor helicopters, is a phenomenon that is very pronounced in the AH-1 series helicopter with its teetering main rotor. This condition occurs as a result of increasing or decreasing main rotor system induced drag while maneuvering, which in turn increases or decreases the rotor system's torque demand upon the engine through the fuel control governor. While airspeed has some effect on transient torque, the primary drivers of this phenomenon appear to be roll rate and/or roll acceleration. This condition, or its potential effects, severely inhibits pilot aggressiveness while performing air-to-air maneuvers. Typically, left rolling maneuvers, high power dives, and left directional turns significantly increase engine torque, which may result in transmission and drive train overtorques and eventual transmission and drive train damage.

The aggressive turn rates, high angular accelerations, and abrupt load factor buildup rates produced during air combat required the AH-1S pilot to continuously monitor engine torque and modulate the collective stick control in order to maintain torque within limits. The test aircraft was modified with a collective stick shaker set to engage at an indicated torque of 85% (Appendix A). Pilot comments were very positive on the improvement the stick shaker provided in managing torque while maneuvering "heads out of the cockpit," but were negative on the usefulness of an instrument panel overtorque light during the air-to-air engagements. The production overtorque light is designed to come on whenever engine torque is greater than 100 + 0.5% and go off whenever engine torque decreases below 96 + 0.5%. All of the overtorques documented via telemetry data except one were never seen by the crew. This was attributed to either the inherent dampening of the torque gauge or the fact that the crew's attention was outside the cockpit while maneuvering. As a result of this problem, the overtorque light was modified to stay on whenever engine torque exceeded 100 + 0.5%, thus allowing the crew an after-the-fact indication that engine torque limits had been exceeded when their attention returned to the cockpit for an instrument cross-check. Still, five overtorques (based on engine differential pressure telemetry readings between 62 psi (100% torque) and 70 psi (113% torque)) and twelve advisory calls (torque greater than 95%) from the ground telemetry station occurred. A lag or damping in the cockpit torque gauge (which is the official means of recording overtorques) in sensing the engine torque was evidenced by the telemetry recorded torque pressures in excess of 100% and the simultaneous lack of a torque limit light indication from the cockpit.

Figure 57 (event 7B, Appendix I) is a composite time history of an AH-1S side-by-side (initial condition) engagement with the AH-64A which shows the relationship between roll rate/acceleration and transient torque response for a collective fixed maneuver. The phase relationship between pilot input, roll rate, and engine torque shows that the commanded roll rate is generating a torque transient which the pilot attempts to control

by using out-of-phase collective stick inputs. Even with the crew's high experience level in both aircraft type and air-to-air maneuvering (Table 7), a 16% overtorque occurred which required the flight to be terminated and a maintenance inspection performed prior to the next flight. Torque management, that is, overtorque avoidance, overshadowed the primary flying tasks and at times demanded the pilot's complete attention during air-to-air engagements. Torque management was made even more difficult by the overdamped torque gauge which, perhaps by design, did not portray the higher transient torque values seen from the telemetered instrumentation. Representative time histories depicting the additional pilot workload generated by this phenomenon for two ACM engagements are presented in Figures 58 and 59. The transient torque generated during maneuvering is nonlinear and is dependent on pilot technique.

A review of Figure 39 indicates that even though each aircraft flew at 95% of its maximum gross weight (except the AH-64A which flew at 92%), the nonexistent transient torque capability of the AH-1S forced the pilot to artificially limit his power applications. The pilots of AACT IV aircraft with good transient torque limits, like the SA-365N-1, were able to maintain high power settings at levels greater than 80% of installed power during approximately 67% of total AACT IV engagement maneuvering time. Good engine/gearbox and transient limit capability allows the pilot to utilize 100% of the aircraft's installed power aggressively. The unpredictability in the magnitude of the AH-1S torque fluctuations required the pilots to very closely monitor engine torque, severely hampered the aggressiveness with which the AH-1S was maneuvered, increased pilot workload, and reduced the crew's effectiveness during the air-to-air engagements.

To fight and win close-in air-to-air engagements, the crew must be able to aggressively maneuver without damaging the airframe. To accomplish this, the airframe must have good engine/drive train compatibility with the capability to accept transient loads without damage. While torque cueing as integrated into the AACT IV AH-1S helped the situation by forcing the pilot to compromise or inhibit the maneuvering that he wanted to do, it is not the answer to the problem. Tactile and cockpit visual indicators such as the stick shaker, overtorque light, and torque gauge are neither entirely sufficient to compensate for inherent vehicle design limitations in the ACM environment nor reactive enough to allow the pilot to maneuver aggressively and avoid airframe structural limitations with possible component damage.

Airframe structural limitations, like poor transient power capability and inferior performance, significantly inhibit the maneuverability of the aircraft and thus its air-to-air combat potential. Integration of a digital electronic fuel control like the adaptive fuel control developed under the direction of AATD has the potential of providing overtorque and overtemperature protection throughout the aircraft's maneuvering envelope, reducing pilot workload, and allowing the pilot to aggressively use the 20 to 30% of installed power that he is currently inhibited from using in aircraft such as the AH-1S.

SA-365N-1 "Jack Stall." The basic flight control system of the SA-365N-1 helicopter consists of mechanical linkages and hydromechanically boosted servo-actuators that position the main rotor swashplate as commanded by the pilot. The condition known as jack stall occurs when the aerodynamic forces acting on the rotor blades overcome the capability of the flight control servo-actuators. These aerodynamic forces are transmitted through the mechanical linkages directly to the pilot's controls and can easily exceed his physical capabilities to move the controls. During AACT IV, jack stall occurred with accompanying cyclic control migration in the SA-365N-1 at high speeds (150-175 kt) after abrupt aft control movements were applied, and at lower airspeeds (approximately 80 kt) during aggressive maneuvering.

As shown in Figure 60, jack stall occurred after the pilot initiated a left turn during a recovery from an aggressive pull-up maneuver. At approximately 9.3 seconds on the time history traces of Figure 60, the cyclic control performed an abrupt, uncommanded by the pilot, migration from a forward (8% from the forward stop) and left (37% from the left stop) position to just past the control's centered position (58% and 54%, respectively). The pilot was unable to move the cyclic control for approximately 0.5 second, and once the flight control system became effective, took several seconds to regain control of the aircraft and allow uncommanded aircraft motions to subside. The air-to-air engagement in question was terminated by the SA-365N-1 pilot when the jack stall was encountered. The occurrence of jack stall within the operational flight envelope of the SA-365N-1 is unsatisfactory for the aggressive maneuvering required during one-on-one air combat.

Field of View

Restrictions to both aircraft and helmet FOV must be minimized: "You can't fight what you can't see." AACT IV reiterated the fighter pilot axiom, "lose sight, lose the fight." No helicopter participating in AACT IV had an FOV that was entirely adequate for air-to-air fighting, although visibility from tandem seating aircraft was shown to be inherently better than that from side-by-side seating vehicles. However, the Apache (tandem) with its canopy frames and circuit breaker panels was not much better in terms of FOV than the Dauphin (side by side). The most effective mission equipment package (MEP) coupled with an exceptional turn performance capability will not help win the fight if the pilot loses sight of his adversary and turns the wrong way.

Restrictive FOV repeatedly prevented rapid initial acquisition/engagement and often caused LOS loss during the engagement, which allowed the adversary to maneuver to a superior position and successfully engage his target. Inadequate FOV can compromise the effectiveness of a superior tactical maneuver. Limited FOV requires the pilot to more aggressively maneuver his aircraft, that is, use higher attitudes, rates, and accelerations than might otherwise be required to keep LOS on the bogey. The AH-1S (JAH-1F) with adequate overhead FOV, even though hampered by relatively poor maneuver performance, permitted good defensive tactical piloting. The end result of a better FOV

for the AH-1S was often a draw rather than being "shot down" by a more maneuverable adversary. In short, a vehicle with superior FOV and inferior performance can reduce its susceptibility. In fact, the ROE given in Appendix C were modified during AACT IV to accommodate the recurring situations whereby the crew of one aircraft or the other would lose sight of their opponent, most often due to FOV restrictions. Instead of an automatic "knock it off," the engagement was allowed to continue with the vehicle still in visual contact assuming the responsibility for separation safety. The mosaic presentations in Figure 61 for the AH-64A, Figure 62 for the AH-1S, and Figure 63 for the OH-58D (comparable to the 406 CS) show the relative outside visibility from within the respective aircraft cockpits. (Note: Some truncation in vertical FOV in the AH-1S and OH-58D photographs is a result of camera lens limits.)

An air-to-air capable aircraft with the optimum FOV should have a narrow fuselage, tandem seating (pilot in the front seat), a single piece bubble-type canopy, and a minimum of visual obstructions in all quadrants. Canopies should be nonreflective (glint signature reduction is extremely important) and must be kept clean/scratch-free. Pilot FOV must not be compromised in order to reduce signature. Bubble-type canopies afford better FOV. Large frame supports and/or circuit breaker panels must be reduced if not eliminated from the air-to-air vehicle canopy design. Side-by-side seating is unsatisfactory for air-to-air combat due to severe FOV restrictions. Additionally, a means of improving visibility (mirrors/cameras) to the rear (4 to 8 o'clock position) is desirable. Most real-world aerial combat kills were recorded on "targets" that never saw the attacker.

The aircrew helmet FOV visibility is of comparable importance to that of the cockpit and should not be overlooked. In the opinion of the AACT IV aircrews, the Army SPH-4 and AH-64 IHADSS aviator helmets shown in Figure 64 are unsatisfactory for air-to-air combat. A more lightweight, close shell-to-head fit helmet such as the Air Force HGU-55/P (also shown for comparison in Figure 64) with minimum peripheral vision restrictions should be adapted for air-to-air rotorcraft crews.

Weaponization

Fixed/Turreted Gun Firing Opportunities. In the probing, confusing, swirling world of helicopter air combat, "catfighting" and its attendant tactics will always be required. Targets will always pop up in unexpected quadrants and guns will always be needed for the close-in fight as a complement to missiles and rockets.

One objective of AACT IV was to obtain a maneuverability MOE relative to aircraft pointing and positioning for both fixed and turreted gun firing opportunities. The MOE data was to be quantified in terms of both geometric firing windows and LWS ballistic hit/miss patterns. Unfortunately, at this writing the LWS data for the participant aircraft has not been reduced sufficiently to permit the formulation of any substantial conclusions regarding hit/miss error and thus be a quantitative measure of the pilot's flying/aiming

ability. However, aircraft state and position data gathered during AACT IV provides for computation of the geometric position of the bogey in the "shooter's" fixed and turreted gun window. In addition, the load factor, attitude, and rate activity during the ACM firing opportunity, as well as the aircraft/gun configuration-dependent firing opportunity summaries to be addressed later, constitute a valuable MOE data base.

Air-to-air maneuvering requirements are both defensive and offensive in nature. Defensively, the pilot must first maneuver his vehicle to deny the opponent the immediate opportunity to engage successfully with weapons. If the shot cannot be completely denied, the next best thing is to maneuver the defending aircraft in order to complicate the attacker's gun solution and deny him a good shot while, hopefully, moving to a more advantageous offensive position. While a turreted gun provides increased firing opportunities, it does not mitigate the maneuvering performance essential to at least attain maneuvering parity with that of the adversary for defensive posturing. Aircraft with turreted weapons can intimidate other nonturreted aircraft into spending more time flying defensively, that is, staying out of the turret envelope. The end result in this situation is more survivability for the turreted aircraft due to a decrease in the opponent's shot opportunity as a result of being forced to fly defensively. The ownship capability to shoot off-axis thus may deny or at least restrict the opponent's firing opportunities. Development of accurate off-axis fire control solutions for rotorcraft in maneuvering flight is essential for effective counter-air helicopters.

The aircraft/gun configurations flown included the AH-64A (fixed and turreted), the AH-1S (fixed and turreted), the SA-365N-1 (fixed only), and the 406 CS (fixed only). While an ambitious attempt was mounted by BHTI to install and integrate a Lucas turret and a Polhemus HMS on the 406 CS, the technical problems associated with this integration could not be resolved in time for the AACT IV window. The LWS on the AH-64 turret was successfully slaved to both the HMD and TADS. (The fire control ballistic lead computing of the AH-64 was not integrated with the LWS.) A similar LWS on the AH-1S turret was also integrated with a Polhemus HMS. Although both turreted aircraft used an HMS to point the reticle and thus the turret at the bogey, a parallax problem with the AH-1S HMS/LWS was discovered too late to be corrected for the test. The SA-365N-1 employed only a fixed mount LWS. The SA-365N-1 LWS was aimed by a Thomson-CSF HUD, while the 406 CS as well as the AH-64 and the AH-1S LWS in fixed gun mode were aimed (or pointed) by a rudimentary grease pencil cross-hair reticle drawn on the forward wind screens. Although the stabilized fixed forward reticle for the AH-64 HMD was explored for this gun mode, the acute IHADSS (limited to 4 degrees of freedom; no reticle lateral or longitudinal spatial orientation correction) angular resolution does not lend itself to fixed gun application.

The data of Figure 65 clearly reveal the value of a turreted weapon. Even the teetering rotor AH-1S in the turreted gun mode substantially improved its firing opportunities over those in the fixed gun mode. The firing opportunities presented in Figure 65 are expressed as a percentage of the total one-on-one "fights-on" engagement time. Only

those engagements with neutral initial conditions (i.e., no initial position advantage to either combatant) were interrogated for the firing opportunity data. A geometric firing opportunity existed when the LOS to an adversary was within the particular respective turret azimuth and elevation envelopes. For the AH-64, the mechanical turret envelope limits are ±110 degrees azimuth and +11, -60 degrees elevation and for the AH-1S ±110 degrees azimuth and +13, -50 degrees elevation. The fixed gun envelopes were initially treated as ±3 degrees azimuth and elevation for the post-test firing opportunities analysis. However, based on further discussions with the AACT pilots and the lack of conclusive LWS aiming or hit/miss data, both the turreted and fixed gun windows were expanded slightly. This expansion was to account for an inherent transient airframe slew capability that could, by means of a minor step input to the proper control, bring the nose of the shooter aircraft into a fixed gun LOS with the bogey aircraft or reacquire a bogey that migrated just outside of the mechanical turret window. Consequently, the fixed gun window was treated as ±10 degrees in azimuth and elevation for each aircraft except the AH-1S. A ±5 degree fixed gun azimuth was permitted for the AH-1S, based on pilot opinion and lower AACT demonstrated yaw rates. These "airframe slew" firing window expansions were added to the mechanical turret envelopes. However, as few as the fixed gun opportunities may be (in relation to the turreted values), the relative fixed gun percentages do improve with inherent vehicle M&A.

Uncoordinated high sideslip flight conditions were not uncommon in the fixed gun configurations. This condition presents a problem synonymous with the turreted gun off-axis situation which necessitates revamped fire control solutions for the air-to-air role. Aircraft with inferior performance, whether due to type rotor system, gearbox fatigue life or torque limits, or structural limits, are typically revealed in the fixed gun scenarios. The AH-1S accumulated approximately one-tenth the firing opportunities in the fixed gun mode relative to the other AACT IV aircraft regardless of the 5 or 10 degree fixed gun window (Figure 66). The fixed gun scenarios show a greater need for a careful match of yaw control capability and high yaw axis stability. Both the AH-64 and SA-365N-1 clearly demonstrated an improvement over the AH-1S in the fixed gun mode, while the smaller, hingeless rotor 406 CS experienced even better success.

Figures 67 and 68 show histograms of the Apache-to-bogey and Cobra-to-bogey angle-of-sight azimuth and elevation position in the respective turret windows for all engagements. Most azimuth opportunities occur within ±20 degrees of directly forward. The small growth in the firing opportunities at about ±70 to ±90 degrees of azimuth is indicative of the "fur ball" turning fight that develops in trying to acquire and maintain the maneuvering bogey in the ownship's forward hemisphere. The elevation opportunity histograms for these aircraft are also similar at about ±10 degrees. However, the slightly higher percentage for the Cobra in the ±10 to ±20 degree elevation band is likely because the bogey aircraft were able to outclimb the Cobra, thus positioning themselves slightly higher in the Cobra's turret elevation window than in that of the Apache. Figure 18 showed a summary of the scatter and clusters of firing opportunities available to both the Apache and the Cobra (at approximately 0.2-sec intervals) for all

turreted flights. Notice the similarity between the firing opportunity cluster positions and the histogram activity. These scatter plots are, in effect, LOS position plots of the bogey in the respective turret windows. The apparent reduction or lack of concentrated firing points at the zero azimuth (directly forward) LOS position for the Apache and Cobra were not attributed to any particular pilot FOV or tracking problem. The azimuth AOS histogram (Figure 67) shows a higher percentage of engagement time with firing opportunities at the ± 10 degree azimuth window for the turreted gun AH-64A than for the fixed gun AH-64A with the artificial ± 10 degree azimuth window (Figures 65 and 66). However, since the turret ± 10 degree azimuth window also includes the full elevation window of the Apache turret (+11, -60 deg) as compared with only a ± 10 degree elevation window artificially allowed for the Apache fixed gun, the azimuth angles of sight could present turreted firing opportunities but not necessarily fixed gun opportunities. The LOS scatter plots presented in Figure 17 show the position of the bogey in all azimuth and elevation quadrants covering an LOS window of ± 180 degrees azimuth and ± 90 degrees elevation. This full sweep of LOS data indicates the predominant bogey LOS position as well as position extremes relative to the ownship longitudinal centerline. The data in Figure 18 suggests the general extent to which the turret should travel (i.e., mechanical azimuth and elevation limits) to acquire the target bogey the majority of the time, as evidenced by the position and density of the points in these scatter plots. However, the LOS/FOV restrictions of the particular cockpit are very influential on the pilot's incentive to maintain the bogey in the front quadrant in order not to lose visual contact.

The scatter plots for load factor versus azimuth firing opportunity reveal the increase in load factor activity toward the boundaries of the turret azimuth limit as the ownship executes turning maneuvers to realign or maintain the bogey in the turret window (Figure 69). Not unexpectedly, most of the load factor activity during firing opportunities is clustered within the 0.8 to 1.2 "g" band as summarized in the histograms of Figure 70. This suggests that the turret flexibility was used to attain a majority of the firing opportunities (i.e., the positioning task) rather than depending solely on vehicle alignment via M&A to maximize firing window opportunities (i.e., the pointing task). However, shot opportunities with a turreted weapon (as well as fixed) were attempted and attained while maneuvering under much higher "g". Consequently, the functional envelope of the weapon (gun) must include the capability to shoot without weapon mechanical or fire control difficulties at load factors substantially higher than 1 g. Airborne weapons therefore need a functional V_n envelope identified. Also, the crossing rates of two air-to-air combatants are shown in Figure 71 as a function of separation range. The high crossing rates (in excess of 100 deg/sec) within the "catfight" gun range suggest that both the turret mechanical dexterity and the fire control intelligence must be particularly acute to operate effectively in the air-to-air environment.

IHADSS vs TADS. The TADS employed on the AH-64A is very effective for long range detection and acquisition of targets. It contains a combination of three sensors: Forward-Looking Infrared (FLIR), Day TV, and Direct View Optics (DVO), each capable of multiple fields of view (magnification). The TADS turret can be slaved to a monocular HMD while the 30mm cannon (or Saab LWS in AACT IV) can be slaved to either the TADS or the HMD. This integrated system is known as the IHADSS.

The AACT IV data was analyzed by MDHC to determine whether a difference existed between the "manual" IHADSS HMD and the "auto" TADS tracking for the turreted gun system on the AH-64A. The gun system MOE for this comparison was the probability of hit for each gun round.

The tracking modes were compared in two steps. The first step was to obtain probabilities of hit (P_h) while the AH-64A was in both the IHADSS and TADS tracking modes. AACT IV flight trajectories were re-created in the Air Land Engagement Simulation (ALES) model (see Figure 72). As the trajectories were flown, ALES fired the gun when the target was within gun range, turret position limits, and turret rate limits. If the target was within the gun system limits, it was assumed that the tracking IHADSS or TADS was sighted on the target. For each shot, a P_h was determined based on range, miss distance, gun system errors, ballistic errors, and target presented areas. The gun system errors were optimistic, and it was assumed that the tracking systems were operating correctly. The AH-64A's opponent for both the IHADSS and TADS flights was the SA-365N-1 in a fixed-gun firing configuration. The second step was to assess the P_h data with an analysis of variance (ANOVA) multiple comparison test. The ANOVA determined the difference in the average probability of hit between the IHADSS and the TADS tracking. Although several engagements for each of the tracking modes share the same initial conditions, the resulting maneuver trajectories were not duplicated (see Figure 73). Thus, the maneuvers are comprised of random trajectories from which no inferences on interacting factors can be made.

While the AH-64A was in the manual mode, it was assumed that the IHADSS was in use with no inputs from the TADS. This means that no target range, velocity, or acceleration information was computed. The fire control computer (FCC) corrected only for ownship dynamics and ballistic errors. The IHADSS had an uncontrolled error in target position information due to movements of the head. In the auto mode, it was assumed that the TADS was in use with the Image Auto Tracker (IAT).

Information provided by the TADS, which allows computation of target range and velocities, greatly improved the accuracy of target position determination. The "ALES bullets" were assumed to have straight line trajectories to simulate the Saab laser that was used in AACT IV to score gun hits, or more correctly, to score aiming error. The straight line "bullets" were adopted due to the lack of maturity of the Saab laser airborne ballistic representation.

The TADS' ability to track and engage the target results in higher probabilities of hit than the IHADSS. The increased probabilities of hit were due to the FCC's ability to predict the target position at bullet impact based on the target position and velocity from TADS/IAT track data. The increased accuracy of predicting target location resulted in lower miss distances. In addition, TADS gun command error dispersion is much smaller than the IHADSS. As a result, the gun aim point was on target a greater percentage of the time. The reduced miss distances and more accurate aim point sufficed to increase the TADS/IAT's P_h significantly higher than that for the IHADSS.

The reality of the ACM physical situation, however, precipitates somewhat different results. It must be noted that the ALES analysis assumed that the IAT can be used effectively and was locked on the target. Crew comments indicate that it was difficult to acquire, lock-on, and track a target with the TADS/IAT system at the close-in fight ranges. At the short ranges encountered in this type of combat, the importance of a tracking sensor is diminished, while the role of the pilot to fly and shoot dominates. The HMD gun mode was considered to be the best mode for the close-in engagement due to its field of regard and ease of use. The TADS tracking, while the most accurate pointing mode for the gun, was a more difficult mechanism due to the narrow limits of the TADS instantaneous FOV, switchology dexterity and time requirements, and susceptibility to breaking lock-on across contrasting backgrounds.

ALES was not used to examine any of the flights in which the AH-64A had a fixed gun. While the turreted flights were set up to be either IHADSS or TADS flights, the pilot and copilot did not necessarily use only the designated mode. By using ALES, it was possible to "force" the use of only one mode per flight and therefore allow an analytical evaluation of the sighting/tracking modes.

PILOT OBSERVATIONS

GENERAL

The professional observations made by the AACT IV pilots are considered a valuable segment of the overall helicopter air-to-air data base. The commentary presented herein was gleaned from three primary sources: post-flight debriefings, post-flight pilot questionnaires, and post-test pilot reports. These observations may be grouped into two general categories: those concerning the actual conduct of the test with implications to the test data, and those concerning the aircraft ACM characteristics either as demonstrated by the aircraft or as desired by the pilots.

The pilots for AACT IV were selected based on their air combat experience and/or flight time in the particular type of aircraft. The flight crew qualification records for the project pilots are summarized in Table 7. The AH-1S pilot was an Army test engineering pilot from the United States Naval Test Pilot School (USNTPS) with a copilot from the Utah National Guard for the initial part of the test and a Marine engineering test pilot as copilot for the remainder. MDHC engineering test pilots flew the AH-64A. The 406 CS was flown by a BHTI engineering test pilot with an Army OH-58C qualified aviator serving as copilot. An AATD engineering test pilot commanded the SA-365N-1 with an Aviation Engineering Flight Activity (AEFA) engineering test pilot flying as copilot on the first part of the test and a qualified Army Rotary Wing Test Activity aviator completing the test.

The following pilot observations, grouped in four areas - aircraft design, weaponization, tactics, and human factors - are prefaced by a comment made by one of the AACT IV aviators:

> "Army aviation air-to-air combat doctrine development, hardware requirements identification, and program implementation is at about the same stage of development as the rest of the air-to-air aviation community was at the start of World War II."

AIRCRAFT DESIGN

Pilot observations in the area of aircraft design included the following points:

1. Structural load limits can easily be exceeded in the air-to-air environment without knowing it. Published V-n diagrams and dynamic component structural limitations are of little value in the cockpit without onboard systems to monitor/protect the airframe.

2. Cockpit instrumentation in current production aircraft is inadequate for providing the information the pilot requires for the air-to-air mission.

3. The aircraft with the fastest turn rate and smaller turn radius has an advantage. Focus on <u>rates</u>, not <u>g's.</u>

4. Performance means initiative whether on offense or defense. Increased agility, flight speed, and dash capabilities are inherent attributes to the air-to-air design. New generation aircraft with air combat performance enhancements will exhibit improved collateral capabilities in NOE flight as well.

5. Regardless of the lethality of a given weapon system, it is of little value unless it can be brought to bear on the target. Air-to-air combat is a very dynamic situation. Airspeed, altitude, turn rate, and turn radius change rapidly in a very short time. These abrupt air-to-air maneuvers are characterized by frequent maximum control deflections. Any one set of conditions (airspeed, altitude, power) is only maintained for a short duration while engaging an adversary. Precise control of aircraft attitudes, rates, accelerations, and position is crucial if a successful engagement is to occur (i.e., in terms of pointing/maintaining gun and/or pipper with required lead).

6. Aircraft performance, in terms of specific excess power (P_s), and maneuverability are important because of their effect on the attack helicopter's offensive and/or defensive capability for preengagement posturing and disengagement. To effectively acquire, manually track, and maximize firing opportunity (fixed/turreted), the attacker has to continually make small corrections to the aircraft flight path in order to either maintain correct (range/lead) pipper position, maintain the adversary within turret envelope, or deny the adversary an advantage. Handling qualities are also important, particularly short-term response. To be effective in air-to-air combat, the attacker must be able to closely control closure rates (accel/decel) and attitudes (pitch, roll, and yaw) in order to close and engage the bogey quickly and accurately.

7. Engine spool-up time to reach maximum power makes a big difference in engagement, disengagement, and/or reengagement capability. The effects of seemingly small time delays between commanded power and obtained aircraft performance are significant during aerial engagements, particularly when coupled with variations in rotor RPM and its effects on weapon pointing accuracy.

8. The transient power capability and good P_s available to the AH-64A allowed the crew to capitalize on the added firing opportunities afforded by a turreted

weapon. The requirement to initially out-maneuver the opponent in order to negate the adversary's firing opportunities is still required with a turret. Given a turret, a vehicle with superior maneuverability can now dominate the fight. M&A are essential for winning the close-in fight. The turreted weapon provides a distinct advantage but does not mitigate the requirement for maneuverability, agility, and excess power.

9. In the close-in battle, inferior performance cannot be compensated for by just a turret. Although the JAH-1F (AH-1S modified for flight test) with a turret was a challenging adversary because of the skill of the AH-1S pilots, the AH-64A with its turret and transient power/torque capability presented a far greater adversary. Even with a turret, however, the JAH-1F's inferior performance reduced its firing opportunities and allowed the other AACT participant aircraft to usually outmaneuver (in the vertical climb and horizontal turn dimensions) and thus use the JAH-1F's own rotor disk for masking.

10. Good engine/gearbox compatibility and transient limit capability allow the pilot to utilize 100% of the aircraft's power and torque envelope without worry of structural damage caused by the dynamic loading of particular components. Aircraft with poor or nonexistent transient capability could not be as robust in their maneuvering and frequently wound up at a disadvantage with little or no possibility of reversing the situation.

11. Early identifiable weak links in helicopter ACM are the tail boom and the tail rotor dynamic components, and the yaw axis control power. Better directional agility and better roll performance were desired by all crews.

12. From a hover, large sideward and rearward speed envelopes were a tremendous advantage and resulted in increased target tracking opportunity/time.

13. Pilot confidence in being able to demand the aircraft's maximum capability without damaging the aircraft (or oneself) is of paramount importance. Throughout AACT, real and perceived hardware limits inhibited aircraft performance. The vehicle capability to monitor and communicate to the pilot the health of critical airframe and dynamic components is crucial. Flight recorders to monitor real-time flight loads and critical parameters are a must. Soft limits for normal operation (with pilot override capability and warnings at endurance limits) and hard limits for ultimate performance situations (that require component replacement and inhibit further increases in maneuvering loads at static limits) need to be identified/monitored.

14. Effective engagements (i.e., rounds on target) should be possible throughout the full range of aircraft performance capabilities. Air-to-air rotorcraft need an integrated fire/flight control system that permits effective engagement and reduces pilot workload when both the firing platform and the target are moving. Adverse aircraft dynamic characteristics, for example, main rotor speed (N_r), overspeed, dig-in and/or droop, manifest themselves particularly during the dynamic maneuvering conditions required to get or avoid the kill in a close-in gun battle. Uncommanded deviations in aircraft pitch, roll, and yaw attitudes/rates/accelerations must be kept to a minimum if fire control solutions are to be available to the copilot/gunner (CPG).

15. Visual detection and identification of adversary rotorcraft is an important tactical consideration and will include issues such as size of vehicle and rotor system characteristics. Visual features include canopy glint, rotor blade glint flicker, and airframe signature. Aircraft size, number of blades, and even paint schemes can influence the visual signature and, as such, disguise the aircraft maneuvering intentions to the threat. A physically small bogey aircraft makes it difficult to acquire, drives the fight closer for visual identification friend/foe (IFF), and makes it harder to discern the bogey's current maneuver state. This increases pilot and CPG workload since the aggressor cannot take his visual sensors (eyes) off the target. The ability of the pilot to visually acquire and keep LOS with an adversary is one of the most important ingredients in aerial combat. Rotorcraft design features for maximizing FOV include:

    - tandem seating - pilot in front station
    - narrow fuselage
    - single-piece bubble canopy with minimal obstructions to pilot/CPG FOV

WEAPONIZATION

Pilot observations in the weaponization area were as follows:

1. Bullet dispersion pattern may need to be varied as a function of range to target. That is, as the range to the target increases, the round-to-round dispersion should be increased to cover a wider area at the range of the target.

2. The close-in engagement compresses the time between target acquisition, target identification, maneuver, and engagement. To be successful, the pilot must optimize his maneuver to minimize the weapons delivery timeline. The ability to detect, acquire, identify, and engage first is crucial. The weapon system must be lethal and easy to use. The weapon system may be considered a composite of actual weapons, ammunition, gun platform

characteristics (aircraft), sight, fire control system, and the aircrewman firing the system.

3. In a one-on-one side-by-side initial condition scenario, the turreted weapon provides an obvious great advantage in shot opportunity.

4. Gunnery systems components must be able to withstand high vibration levels, generate high slew rates, and generate vivid, easily discernable display imagery.

5. HUDs (for fixed forward weapons) and HMDs (for turreted weapons) are a must. Pilots cannot afford to look inside the cockpit in air-to-air combat. The aircraft and its systems must be designed to allow pilots to engage in air-to-air combat maneuvering with eyes out of the cockpit without unknowingly exceeding real airframe or dynamic component limits. Accurate HUD/HMS aiming systems, fast fire control lead computation, and manageable switchology should be required for all aerial combat systems.

6. Systems designed to detect ground targets with relatively low crossing rates need to be optimized for air-to-air combat. The enhancements required for air-to-air will in all probability also enhance its air-to-ground capability.

TACTICS

The following pilot observations were made in the tactics area:

1. Must be able to maneuver in all axes to defeat the immediate airborne threat. The maneuver envelope latitude (g's, roll reversals, etc.) must be such that the ownship aircraft can be totally unpredictable. Another attack helicopter is a lot more dangerous than the possible threat of ground-based air defense artillery (ADA). Use of the vertical greatly enhances pilot options. Three-dimensional maneuvering will always beat two-dimensional maneuvering. The advantage in a close-in fight will belong to that aircraft which not only can turn with agility but can also maneuver vertically to defeat the opponent's weapon solution while positioning for an advantage. The vertical and/or skewed (slightly less than vertical) loop is a possible counter to an aircraft with superior turn rate (analogous to angle versus energy fixed-wing fighter). The capability to judiciously use the vertical dimension plus the addition of a turret greatly enhances shot opportunity as well as defensive tactics options.

2. A design philosophy that advocates denial of a potentially significant number of air-to-air chance encounters or encounters due to aggressor armed helicopter offensive operations will significantly impact friendly fleet

helicopter readiness and ultimately its survivability. Without a doubt, the closer the fight, the lower the probability of survival for both aircraft; however, the pilot still needs the capability to fight the close-in engagement and win. Regardless of system capabilities, chance encounters will happen often--they do in closely controlled airspace in peace time! Trade-off of this close-in fight capability is unacceptable to the flight crews who have to go out, strap on the aircraft, and fight the battle. To quote a flight-crew member: "I take very seriously and personally analyses/trade-offs which show that only 10 to 20% of all encounters will be by chance and therefore are not worth the investment/commitment required to provide a vehicle with the airframe capability to engage and survive the close-in fight."

3. It is apparent that the key to optimizing ownship aircraft survivability/kill potential (P_k) is dependent on using all available maneuvering capability to deny the adversary a shot and neutralize the adversary. Unless total surprise is in favor of the "blue" aircraft, the pilot's efforts must be to first defeat the opponent's firing solution while maneuvering for his own weapon solution. Few good quality shots were taken at the highly agile AACT helicopters.

4. The ability to understand and efficiently use the maneuvering energy of the aircraft is critical to surviving aerial combat with an equal or superior adversary. Understanding your own vehicle strengths/weaknesses and maximizing the strengths is the key to success. Take for example the AH-64A's superior power to that of the SA-365N-1. Although parity in agility/maneuverability appears evident, by zooming wings level the SA-365N-1 could deny the AH-64A the overhead power advantage.

5. Due to the expected lethality of the event, it is best to avoid the helo vs helo close-in fight.

6. The best defense against a gun is staying outside of its effective range. With an advantage in speed, the defender can use his speed capability to either stay beyond the attacker's effective gun range if early detection permits, or once engaged, to maneuver as dead astern of the attacker as possible, accelerate to maximum speed, and fly to terrain masking or exit the area as rapidly as possible until the defender is no longer threatened. This turn and run strategy might, however, present an opportunity for a missile shot from the threat before sufficient range or terrain masking is achieved.

7. ROE for targets beyond visual identification (VID) must be considered.

HUMAN FACTORS

Pilot observations in the human factors area include the following:

1. Pilot ability is a critical factor in determining success/failure in air-to-air combat. Success depends on knowing your adversary, having a plan prior to the engagement, and executing the plan aggressively. While development of effective tactics is important, all aspects relative to aircraft performance capability and design, including total familiarity by the pilot with his own aircraft and weapons system, are essential for success.

2. Crew fatigue is a major factor in air-to-air performance. The normal combat tempo could compromise effectiveness and safety. Additional work in human factors areas such as seat optimization, helmet design and weight (to improve stability of HMS under g's), vibration reduction, temperature control, and development and display of better air-to-air symbology need to be investigated. Crew workload in piloting, targeting, communicating, etc., needs to be reduced wherever possible. The perceived difference in flying in the fixed versus turreted modes is dramatic, physically and mentally.

3. ACM piloting proficiency is a highly perishable skill that requires frequent refreshing.

4. The collective stick shaker on the AH-1S proved to be a valuable tactile aircraft envelope (torque) limit cueing device.

CONCLUSIONS

GENERAL

The Aviation Applied Technology Directorate's Helicopter Maneuverability Program has generated a valuable data base on the use of existing helicopters in both turreted and fixed-gun, one-on-one, air-to-air scenarios following current tactics. In general, pilots flew to the maximum power and thrust limits available - except in those helicopters equipped with teetering rotor systems which were flown with appropriate safety margins due to the possibility of encountering mast bumping and/or overtorques.

A complete structural loads survey and fatigue analysis based on the AACT IV data for the AH-64A Apache by MDHC is available.[11] A similar technical report for the 406 CS was prepared by BHTI.[10] Given that the AACT participant aircraft were not designed for the air-to-air environment, the AACT data base and subsequent contractor reports have nevertheless been instrumental in identifying shortfalls in current aircraft design criteria for ACM airframe loads.

Limited structural loads data on the UH-60 and Sikorsky AUH-76 were obtained during AACT II to determine the extent of any fatigue damage that may have been sustained, its impact on component replacement time, and any impact that air-to-air combat might have on future structural design requirements. Neither aircraft was flown at its critical loading condition from a structural design envelope standpoint. The AUH-76 was flown well inside its center-of-gravity limits and exceeded its design limit load factor only a few times. The UH-60 was flown very light and its load factors remained within the structural design limits. However, the maneuvers flown by both aircraft resulted in loads high enough on certain components to accelerate replacement time.

The following conclusions were derived from the AACT IV data records, pilot commentary, and the AACT data base. They are most applicable to one-on-one close-in air-to-air engagements.

1. The AACT scenario provides a consistent test method of producing stringent ACM flight loads and performance data of candidate rotorcraft for evaluating M&A issues.

2. The AACT scenario did not present a reasonable forum to test the attributes of high airspeed capabilities or large airspeed differences among combatants. Helicopter vs helicopter air combat maneuvering is very "lethal". Once the fight is joined, there is little chance of disengagement except by terrain, weather, wingman, or pronounced speed advantage (+30 kt). Aircraft (systems) and tactics should be developed to win the aerial fight prior to the

close-in (gunnery) stage. Although the fight is inevitable in a conventional battlefield conflict and should be anticipated in design requirements and tactics, the frequency of occurrence is continuously debated.

3. No attempt was made in this test program to address the issues of either crew size (1 or 2 aircrew) or specific weapon characteristics.

4. Aircraft must be either robust, i.e., able to tolerate "over condition" events, or self-limiting, i.e., able to monitor and discipline envelope parameter excursions. The pilot must not be burdened with monitoring, maintaining, or preventing limit exceedances.

5. The AH-1S vehicle displayed a transient overtorque propensity which decreased its ACM effectiveness.

6. The dynamic shortfalls or deficiencies of threat aircraft, synonymous with deficiencies exhibited in AACT IV (e.g., overtorque (AH-1S) and "jack stall" (SA-365N-1)), are key intelligence information that is important to know in order to knowledgeably drive (if possible) the adversary into a problem area. Conversely, ownship maneuvering deficiencies must be known and avoided.

7. The ability to attain and control attitude excursions and large angular rates is important, including the ability to accelerate and decelerate at near-constant body attitude to more effectively maintain combat initiative. Roll attitudes between 90 to 120 degrees and pitch attitudes approaching ± 90 degrees would not be unrealistic. Also, 75-degree/second roll rates, 50-degree/second pitch rates, and 60-degree/second yaw rates have been effectively demonstrated and are fundamental requirements of an effective air-to-air helicopter.

8. Generous load factor and sideslip envelopes are extremely prudent for ACM rotorcraft. Sustained and transient load factors of 3.0 g and 4.0 g, respectively, should be available. An advanced counter-air vehicle should be able to fly 40 to 50 degrees out of trim for 5 to 10 seconds (i.e., uncoordinated requirement) at typical best maneuvering speeds.

9. Rapid turn capability through a given heading change, large power margins (including rotor capability) to sustain a 3 g turn at sea level standard at minimum power speed, and unlimited static sideslip capability are fundamental requirements for an effective air-to-air helicopter. Demonstrated ACM turning performance suggests future ACM requirements at the following levels: 50-degree/second transient and 40-degree/second steady at best maneuver speeds (indicative of load factors of 3.5 g transient and 3.0 g

steady), and 40-degree/second transient and 30-degree/second steady at V_H speeds (suggestive of 4.0 g transient and 3.5 g steady).

10. A small, low inertia airframe promotes both low visual detectability as well as good turn performance, as evidenced by both the BHTI 406 CS and the MDHC 530 (AACT III). Even in prebriefed initial setup conditions, location of a small bogey aircraft (e.g., BHTI 406 CS and MDHC 530) became difficult at times. A reliable IFF system is a must for operations involving helicopter air-to-air encounters.

11. Abundant excess power or a large available maneuver power margin is paramount. Rates of climb at speed for best climb should attain or exceed 4000 feet per minute at combat mission gross weights.

12. Aircraft yaw axis demands present key structural and performance weaknesses for the ACM environment. A vehicle designed for ACM must possess yaw axis agility and robustness not unlike that displayed by the SA-365N-1.

13. Air-to-air maneuvers may have a significant impact on component replacement times and structural design criteria for future aerial combat helicopters.

14. Flapping excursions for the AH-1S with hub spring (with 540 blades in AACT IV) were generally less extreme than without the device (with K747 blade in AACT III).

15. An HMD appears to be a viable display medium to provide the pilot with essential data during the close-in fight.

16. The AH-64A TADS, although of great value in the early acquisition stage of an aerial engagement, has some limitations in a close-in fight.

17. The turreted gun is a significant advantage in an ACM but does not mitigate the requirement of maneuver performance equivalent to that of an adversary. The value of the turret is clearly indicated by the post-processed firing opportunity data. However, no specifics of turret mechanical envelope limits are offered herein. The functional envelope of the weapon (gun) must include the capability to shoot without weapon mechanical or fire control difficulties at load factors substantially higher than 1 g.

18. An unobstructed fixed-wing-type FOV is of paramount importance in aerial combat. FOV for pilot and CPG should be maximized, including both helmet peripheral FOV and cockpit visibility with a minimum of visual obstructions to the rear.

19. In general, to be most effective the helicopter must be point-designed for air-to-air combat maneuvering. Such a vehicle must have advantages in speed (to dash to or away from the battle position), maneuverability (for the close-in fight), agility (for agile ingress/egress and nimble response to avoid threat point fire weapons and to bring own weapons to bear), acceleration/deceleration (to improve combat effectiveness and decrease susceptibility), and durability (to withstand airframe and dynamic component ACM fatigue damage).

SHORTCOMINGS

The following shortcomings were identified during the tests:

1. Simplistic grease mark "pippers" on the forward wind screen for fixed gun aiming for the 406 CS, AH-64A, and AH-1S, while inconsistent with the overall test sophistication, were reasonably effective.

2. Test points for the ATAS platform (406 CS) in air-to-air engagements should have been initiated at closer ranges to the target helicopter to induce more severe 406 CS maneuvering requirements to pursue the target and to more stringently tax missile lock-on and tracking capability.

3. AH-1S (JAH-1F) HMS/LWS boresighting, laser ballistics, and HMS display never fully integrated successfully.

4. The 406 CS software problems prevented operation in the HMS/turret mode.

5. The influence of different piloting skills was not assessed.

6. Lightweight dummy wing stores did not degrade turning performance of the AH-64A as severely as would full-up mission stores. The AH-1S carried no wing stores.

7. The LWS produced no "firing" recoil impulse or vibration. Also, there was no accounting for LWS bullet drops or jumps due to relative wind effects, and no ballistic correction for normal acceleration from either turning aircraft or turret. Further, FOV of the laser lock-on scan pattern proved too small for effective air-to-air utilization.

8. The SA-365N-1 HUD impeded the pilot's visibility, which is very important in the air-to-air environment, and presented a perceived safety hazard with its fixed position only 7.25 inches from the pilot's head. Also, the HUD used was not integrated to transpose the aircraft's critical parameters onto the display. With the pilot's eyes constantly out of the cockpit, critical parameters

such as airspeed, altitude, torque, and rotor speed need to be positioned where the pilot can monitor these measurements without bringing his eyes into the cockpit.

9. The calculations for target-lead pipper performed by the SA-365N-1 HUD and AH-1S HMS assumed LOS aiming input data from the LWS. However, the LOS computation data was tainted with ballistic droop due to gravity. The data received from the LWS was therefore skewed for proper lead and elevation computing.

10. The testing was conducted over a period of 6 weeks during which 14 days were lost due to weather, 1 day was lost due to "foreign object damage (FOD) prevention walk-down" of the airfield, plus there was a 2-day break for a holiday. Initially, AACT IV received a 2-hour early morning (exclusive use) test window over the NATC airfield. This type of arrangement proved to be inadequate. However, during the last week of testing an additional afternoon (nonexclusive use) test window was sanctioned.

11. The absence of terrain and forward area air defense (FAAD) elements in the test scenario, perhaps unrealistically, forced the "fight" to the vertical. The g-envelope utilization in the AACT ACM data base tends to deemphasize the low-g region since terrain masking was not a factor. The ability to gain the "perch" and out-turn the adversary was the key in the 500 to 2000 foot free engagement region.

12. The LWS data has not yet been thoroughly interrogated for the desired quantitative information necessary for accurate vehicle and weapon positioning and pointing task determination. However, geometric firing window opportunity analysis based on turret pointing data and vehicle space position data has proved a valuable preliminary discriminator.

RECOMMENDATIONS

As a result of the AACT IV tests, the following recommendations are made:

1. For future tests of this nature, both the vehicle gross weights and the flight crew skills should be normalized. Selected flight profiles (structured one-on-one and free one-on-one) should be repeated with different aircrews.

2. Follow-up ACM testing is required for FM 1-107 maneuver implications with regard to structural loads and fatigue spectrum, including comparison of same with similar AACT results. Fleet training impact must be defined.

3. "Real" rearward and sideward flight limits for the Apache need to be determined.

4. "Usable" yaw, pitch, and roll rates in terms of both pilot functional limits, rotorcraft structural limits, and rotorcraft achievable limits need to be defined.

5. Tests should be devised to study the implications of speed during the one-on-one scenario, including the phases of detection, pre-engagement maneuvers, and close-in engagement and disengagement, as well as the implications of evasive terrain flying on M&A, loads, and performance.

6. The air-to-air maneuvering overtorque tendencies of the AH-1 need to be parametrically documented via simulation and flight test. Also, there is a need to identify means to either better reveal imminent overtorque situations or improve the AH-1 robustness to inadvertent exceedances.

7. Based on the highly perishable ACM proficiency of the AACT pilots, even on a day-to-day basis, training in the fleet should be pursued energetically, including FM 1-107 maneuvers, combined crew coordination, and perhaps dedicated adversary units.

8. A repeatable means of determining agility equivalents or agility factors among helicopters should be pursued for current vehicle comparisons and future aircraft evaluations.

9. The AACT data base should be further exploited for specifics of maneuver demands and task margins for attitude dynamics (i.e., defining the margin between vehicle capability limit and limits of maneuvers demanded should also suggest any vehicle/pilot interface inhibiting factors in regions of large available margins).

10. Continued limited in-house analysis of test results, contractual airframe design sensitivity analysis, and additional contractual platform/weapon integration analyses (e.g., integrated fire and flight control) are required to optimize platform and weapon system operational and design requirements.

11. The AACT data base should be made available to contractor and Government agencies desiring to conduct ACM independent research and development or in-house analyses.

TABLE 1. AACT IV FLIGHT SUMMARY

Aircraft	Agility Maneuvers	Buildup Flights	ACM Gun Engagements	Stinger Engagements
AH-1S	16	--	--	--
AH-64A	40	--	--	--
406 CS	40	--	--	--
SA-365N-1	47	--	--	--
AH-1 vs AH-64	--	1	58	--
AH-1 vs SA-365	--	1	38	--
AH-1 vs 406 CS	--	1	--	13
AH-64 vs SA-365	--	2	40	--
AH-64 vs 406 CS	--	1	54	28
SA-365 vs 406 CS	--	2	--	15
TOTAL	143	8	190	56

TABLE 2. AACT IV FLIGHT CONFIGURATIONS

Flight Configuration	Fam Tng (hr)	Range Time (hr)	AH-1S (hr)	AH-64A (hr)	406 CS (hr)	SA 365 (hr)
I. Familiarization/Tng Flts						
AH-1S vs AH-64A	2		2	2		
AH-1S vs 406 CS	2		2		2	
AH-1S vs SA 365N-1	2		2			2
AH-64A vs 406 CS	2			2	2	
AH-64A vs SA 365N-1	2			2		2
406 CS vs SA 365N-1	2				2	2
II. Instrumentation Check Flts						
AH-1S, AH-64A, 406 CS, SA 365N-1		2	0.5	0.5	0.5	0.5

TABLE 2. AACT IV FLIGHT CONFIGURATIONS (Continued)

	Fam Tng (hr)	Range Time (hr)	AH-1S (hr)	AH-64A (hr)	406 CS (hr)	SA 365 (hr)
III. Data Flights						
- Fixed Gun						
AH-64 vs SA 365		1.5		1.5		1.5
AH-64 vs AH-1		1.5	1.5	1.5		
AH-64 vs 406		1.5		1.5	1.5	
SA 365 vs AH-1		1.5	1.5			1.5
*SA 365 vs 406						
*AH-1 vs 406						
- Turreted Gun						
*AH-64 (MT) vs AH-1 (T)						
*AH-64 (MT) vs 406 (T)						
AH-64 (AT) vs AH-1 (T)		1	1	1		
*AH-64 (AT) vs 406 (T)						
*AH-1 (T) vs 406 (T)						
- Fixed/Turreted Gun						
SA 365 (F) vs AH-64 (MT)		1.5		1.5		1.5
SA 365 (F) vs AH-64 (AT)		0.5		0.5		0.5
AH-64 (F) vs AH-1 (T)		1.5		1.5		
*AH-64 (F) vs 406 (T)						
SA 365 (F) vs AH-1 (T)		2	2			2
*SA 365 (F) vs 406 (T)						
*AH-1 (F) vs 406 (T)						
*406 (F) vs AH-1 (T)						
406 (F) vs AH-64 (MT)		1.5		1.5	1.5	
406 (F) vs AH-64 (AT)		1.5		1.5	1.5	
- ATAS						
406 (CFT) vs AH-64 (X)		0.5		0.5	0.5	
406 (CFT) vs SA 365 (X)		0.5			0.5	0.5
406 (CFT) vs AH-1 (X)		0.5	0.5		0.5	
- MCEP						
AH-64A		2		2		
406 CS					1	
SA 365N-1		2				2
AH-1S (w/hub spring)		1	1			
TOTAL	12	24	15.5	21	13.5	16

*Planned but not flown due to unavailability of aircraft or inoperative systems

Notes:

Fixed gun mode for AH-64A implies HMS with floating pipper.
Automatic turret for AH-64A implies full-up TADS.
SA 365N-1 has fixed gun only via HUD. No HMS.

Legend:

(F) - Fixed gun
(T) - Turreted gun
(MT) - Manual Turret gun
(AT) - Automatic Turret gun
(CFT) - Captive Flight Trainer
(X) - Target Aircraft

TABLE 3. AACT IV FLIGHT SEQUENCE

Flight Number	Flight Configuration	Notes
01	AH-64A MCEP	
02	AH-64A (F) vs 406 CS (F)	Aborted after one engagement, 406 CS PCM dropped out
(	406 CS MCEP	
04	SA-365N-1 MCEP	
05	AH-64A (F) vs 406 CS (F)	
06	AH-64A (MT) vs 406 CS (F)	
07	AH-1S MCEP	Tail rotor flapping channel lost; fourteen data points obtained
08	AH-64A (AT) vs 406 CS (F)	
09	406 CS (ATAS) vs AH-64A & SA-365N-1	Bad ATAS boresight
10	406 CS (ATAS) vs AH-64A, SA-365N-1 & AH-1S	
11	AH-64A (F) vs SA-365N-1 (F)	
12	AH-64A (F) vs AH-1S (F)	
13	SA-365N-1 (F) vs AH-1S (F)	
14	SA-365N-1 (F) vs AH-1S (T)	
15	AH-64A (MT) vs SA 365N-1 (F)	
16	AH-64A (F) vs AH-1S (T)	Aborted after three data points; AH-1 tail rotor slip ring failed
17	AH-64A (AT) vs SA-365N-1 (F)	
18	AH-64A (F) vs AH-1S (T)	
19	AH-64A (AT) vs AH-1S (T)	

(F) - Fixed gun
(T) - Turreted gun
(MT) - Manual Turret gun
(AT) - Automatic Turret gun
(ATAS) - Air-to-Air Stinger

TABLE 4. AACT IV AIRCRAFT FLIGHT WEIGHTS (LB)

Gross Weight (lb)	AH-1S	AH-64A	406 CS	SA-365N-1
Maximum	10,000	17,600 (Alternate Mission) 14,660 (Primary Mission)	4,500	9,038 (Alternate) 8,600 (Primary)
Desired	9,500	16,130	4,275	8,586
Actually Flown	9,463	16,222	4,344	8,575

TABLE 5. TEST AIRCRAFT DESIGN CHARACTERISTICS

CHARACTERISTIC	AH-1S	AH-64A	406 CS	SA-365N-1
Max takeoff GW (lb)	10,000	17,650	4,500	9,038
Test weight (lb)	9,463	16,222*	4,344	8,575
Engine rating (hp)	1,800	3,300	650	1,400
MCP (XMSN limit)	1,135 (1,290)	2,828 (2,828)	510 (637)	1,153 (1,153)
Blade chord (ft)	2.5	1.75	0.79	1.263
Blade radius (ft)	22	24	17.5	19.6
No. of blades	2	4	4	4
Blade twist (deg)	-10	-9	-12	10.2
Hinge offset (%)	0	3.8	2.65	3.83
RPM	324	289	395	350
Main rotor type	Teetering	Articulated	Hingeless	Hingeless
Flapping stop (deg)	12.5	9.0	N/A	N/A
Parasite drag (sq ft)	5.5	22.0	9.97	
Blade inertia (slug-sq ft)	1,385	952.2	156.7	373.5
Tail rotor type	Teetering	Semi-rigid	Teetering	Fenestron
TR radius (ft)	4.25	4.585	2.708	1.805
TR area (sq ft)	56.75	66.0	23.04	10.24
No. TR blades	2	4	2	13
TR RPM	1,958	1,403	2,381	4,706
TR tip speed (ft/sec)	739	673	675	745
Inertia				
I_{xx} (slug-sq ft)	2,904	5,190	1,043	11.35 in-lb
I_{yy} (slug-sq ft)	11,883	32,310	3,090	46.4 in-lb
I_{zz} (slug-sq ft)	10,234	31,050	2,361	38.26 in-lb

*Average between alternate mission GW (17,600 lb) and primary mission GW (14,660 lb)

TABLE 6. DERIVED PARAMETERS

PARAMETER	AH-1S	AH-64A	406 CS	SA-365N-1
Test wt/max TO wt(%)	95	92	96	95
Blade area (sq ft)	90	166.5	55.75	325.3
Disc area (sq ft)	1,520.5	1,809.6	962	1,203.2
Blade loading (lb/sq ft)*	111.1	106.0	80.7	111.1
Power loading (lb/hp)*	8.81	6.24	8.82	7.84
Disc loading (lb/sq ft)*	6.58	9.76	4.68	7.51
Blade loading (lb/sq ft)**	105.1	97.4	77.9	105.6
Power loading (lb/hp)**	8.34	5.74	8.52	7.44
Disc loading (lb/sq ft)**	6.22	8.97	4.5	7.14
Solidity	0.0651	0.092	0.0575	0.0676
Rotor inertia (slug-sq ft)	2,770	3,808	627	1,494
Lock number	5.2	9.86	6.1	4.2
Tip speed (ft/sec)	746	726	724	718

*At maximum takeoff gross weight (design value)
**At test gross weight

TABLE 7. AACT IV PILOTS

PILOT	TOTAL FLT HRS	TOTAL FLT HRS/TYPE	REMARKS
CW4 Les Scott (USNTPS)	7148	2000/AH-1S	TPS instructor; MAWTS qualified (Sep '83) AACT I, II, & III experience
CW2 Mike Doyle (Utah Natl Guard)	2423	400/AH-1S	ACM/EVM certified (Aug '86) Gunnery qualified (Mar '86)
CPT Steve Joseph (USMC RWATD)	2600	2000/AH-1J, T, S, W	MAWTS qualified (Dec '83) TPS graduate ('85)
MAJ Waldo Carmona (AATD)	3300	100/SA-365	MAWTS qualified (Oct '85); TPS graduate ('85) Army ACM qualified (Feb '88)
CW4 Joe Lyle (AEFA)	4691	63/SA-365	ACM qualified (Jan '86) TPS graduate ('85)
CW4 "Pappy" Papin (RWTA)	5800	43/SA-365	ACM qualified (Apr '86) Air-to-air experience
Mr. Jim McCollough (BHTI)	5000	100/406 CS 500/OH-58D	BHTI test pilot since '79 Society of Experimental Test Pilots
CW4 Charlie Boss (9th ID)	4945	1326/OH-58C 0/406 CS	ACM SIP (Oct '85); Stinger CFT/OH-58C experience; 81 AACM hours
Mr. "Cap" Parlier (MDHC)	2500	300/AH-64A	TPS graduate; air-to-air tactics instructor Air-to-air experience
Mr. Ed Wilson (MDHC)	4500	450/AH-64A	Experimental test pilot Air-to-air experience

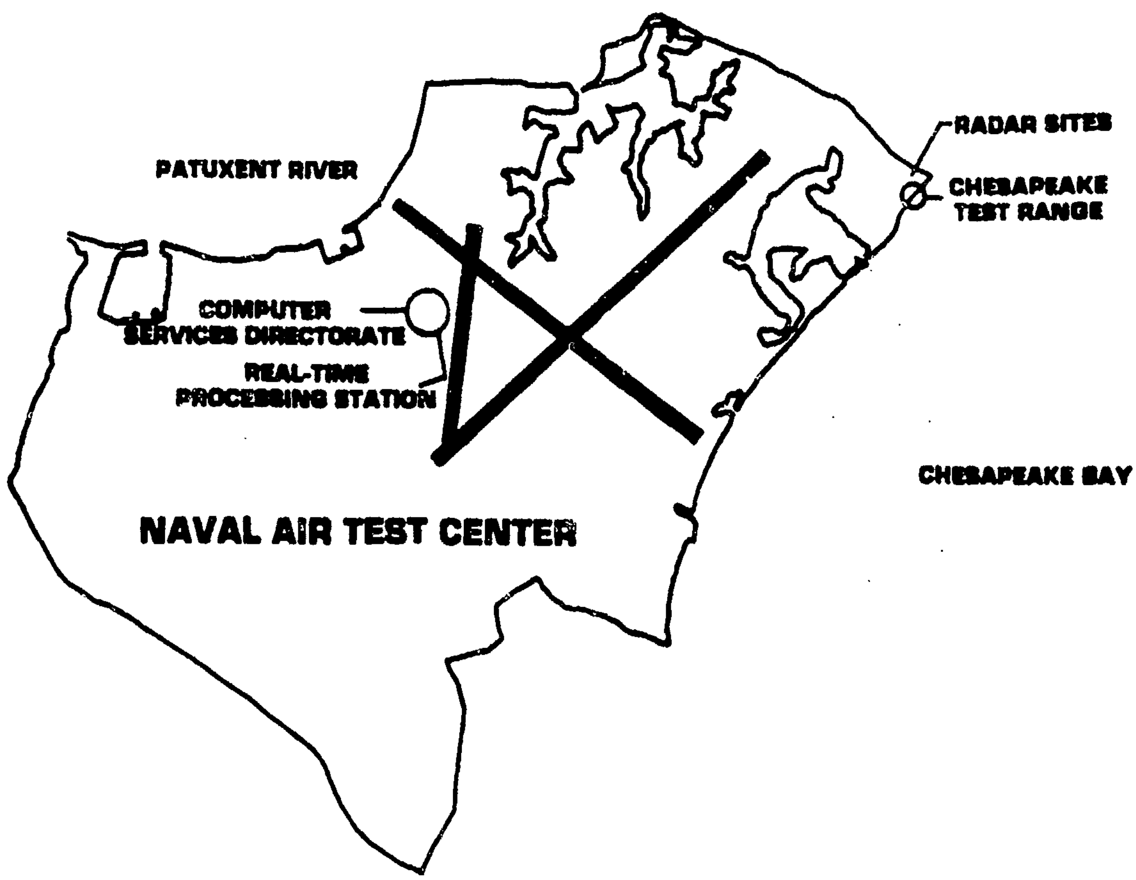


Figure 1. NATC tracking sites and support facilities.

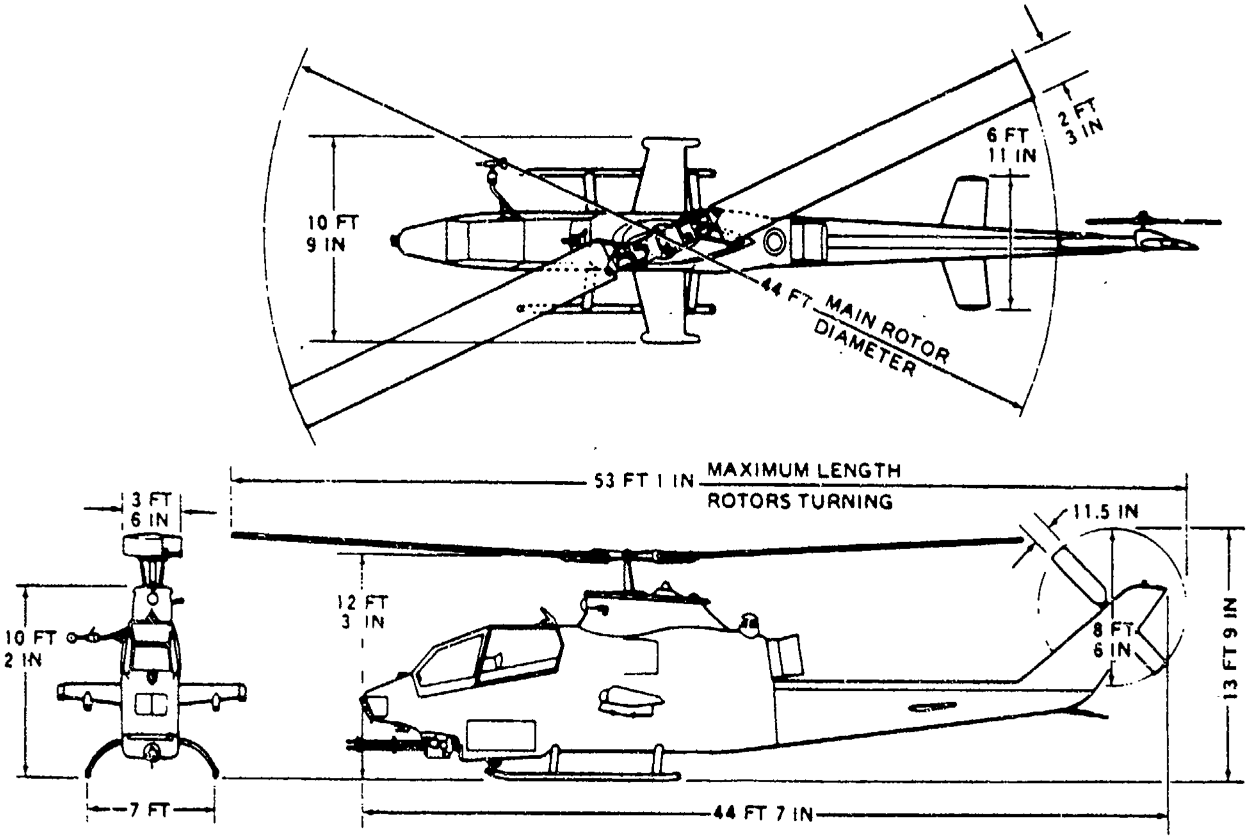


Figure 2. Principal dimensions of the AH-1S (JAH-1F).

Figure 3. AH-1S (JAH-1F) Cobra.

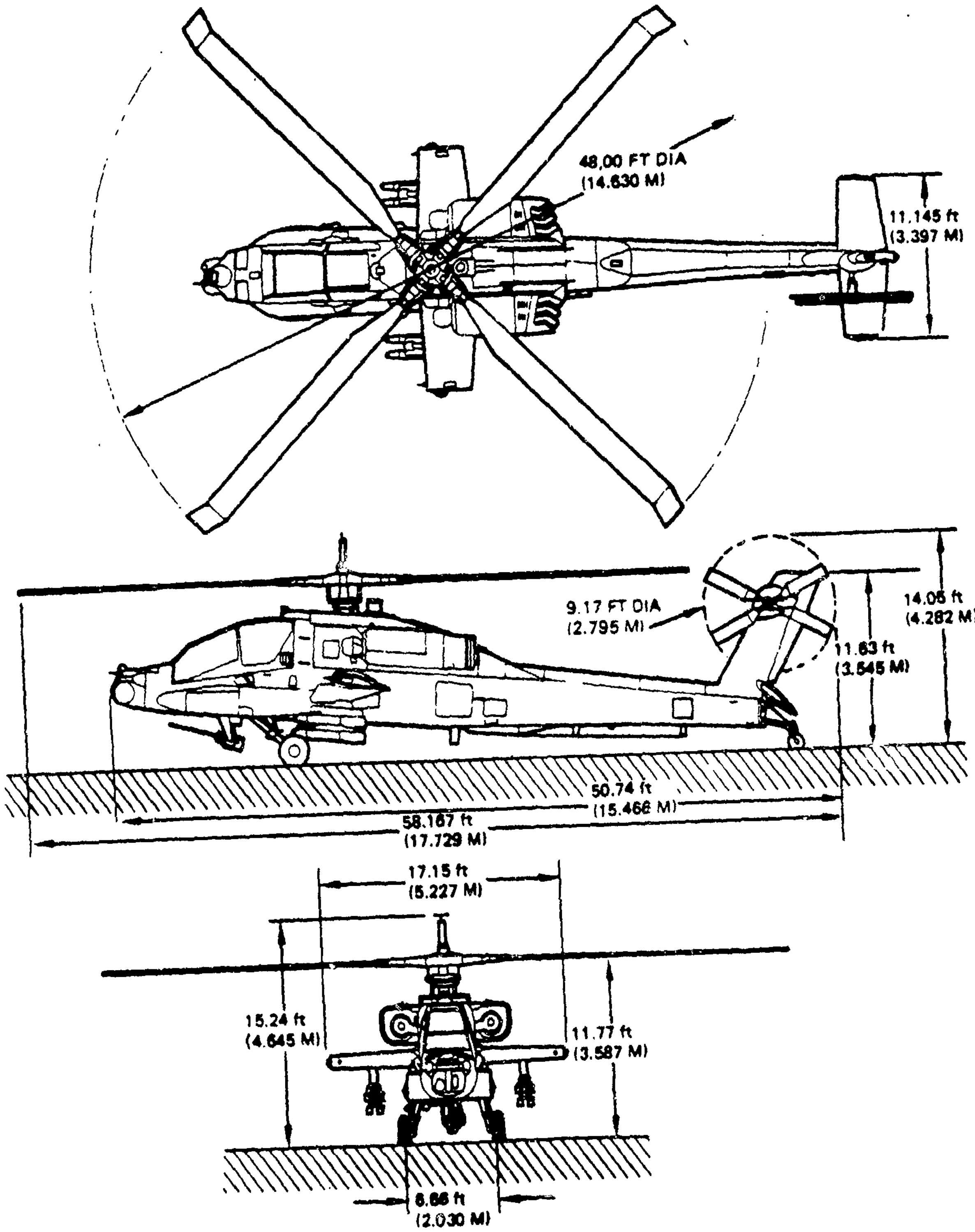


Figure 4. Principal dimensions of the AH-64A.

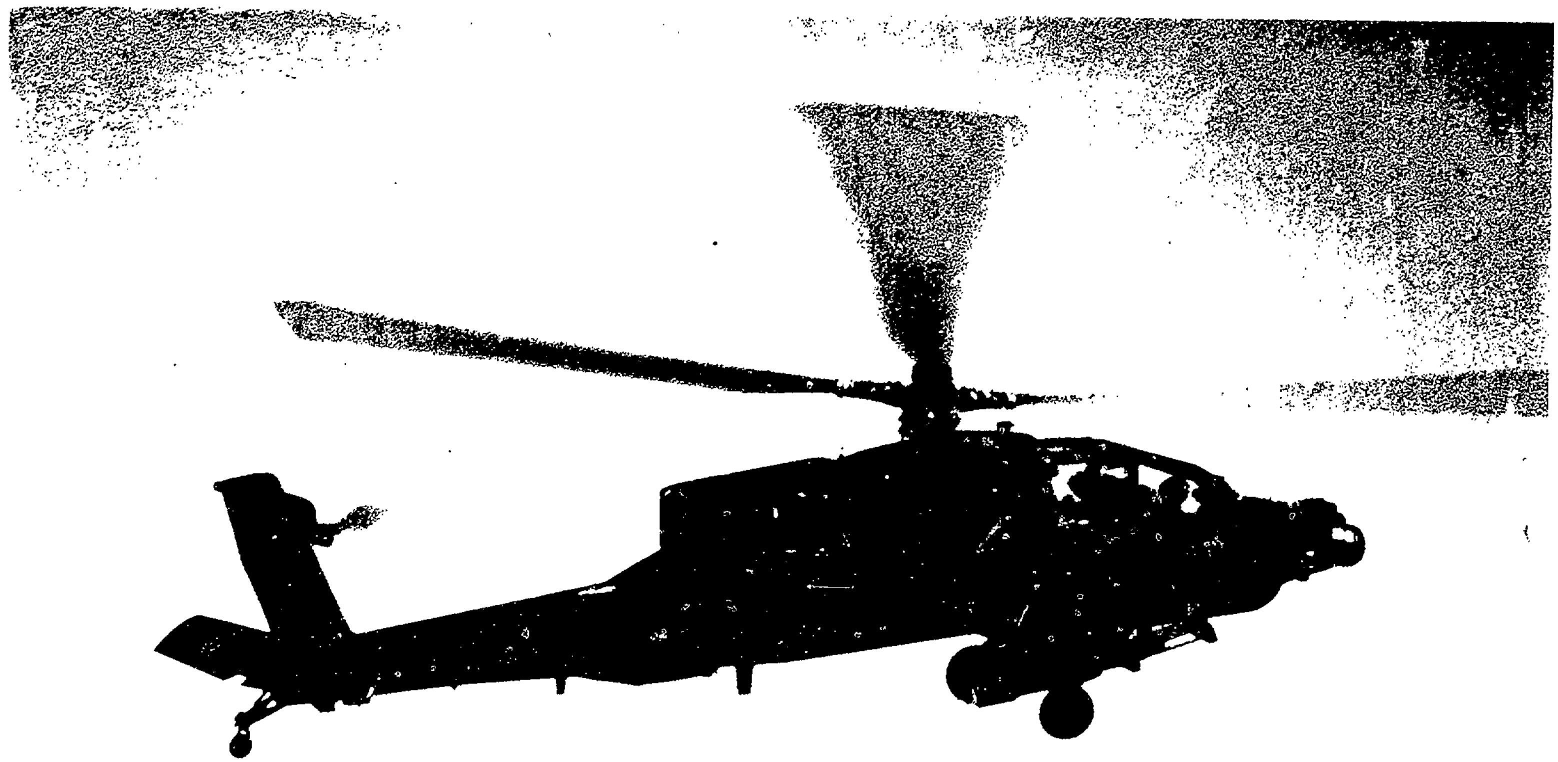


Figure 5. AH-64A Apache.

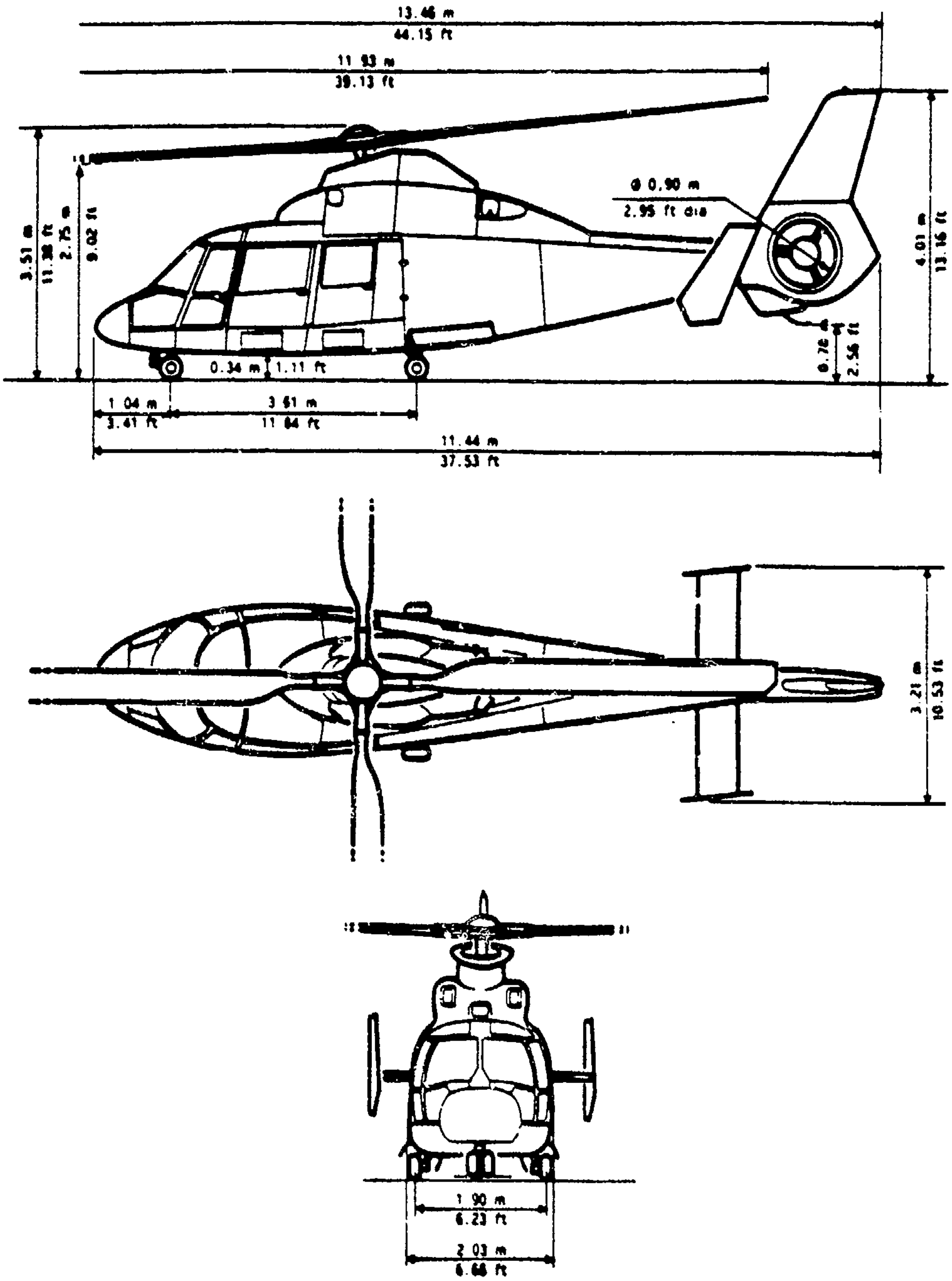


Figure 6. Principal dimensions of the SA-365N-1.

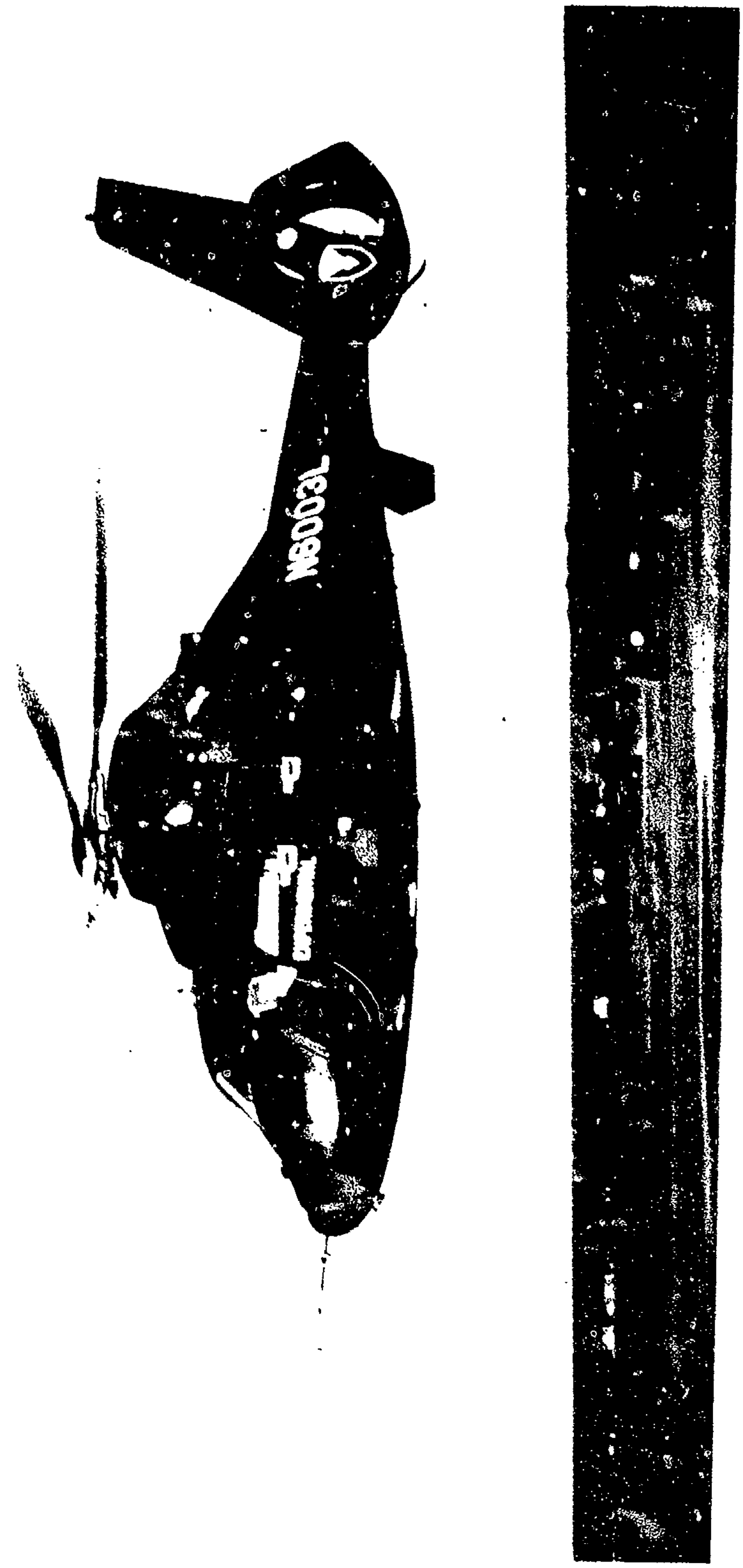


Figure 7. SA-365N-1 Dauphin.

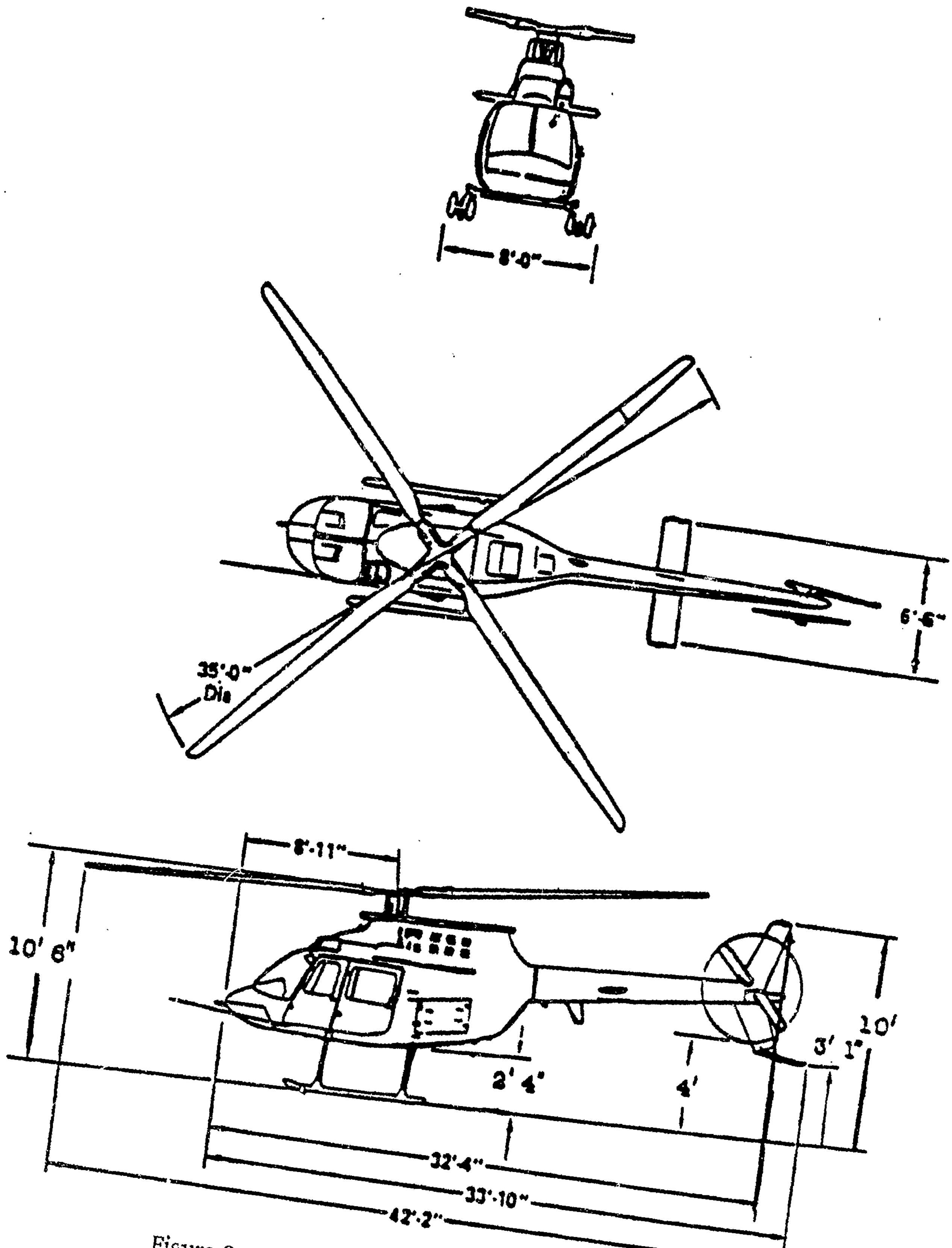


Figure 8. Principal dimensions of the Bell 406 CS.

Figure 9. 406 Combat Scout.

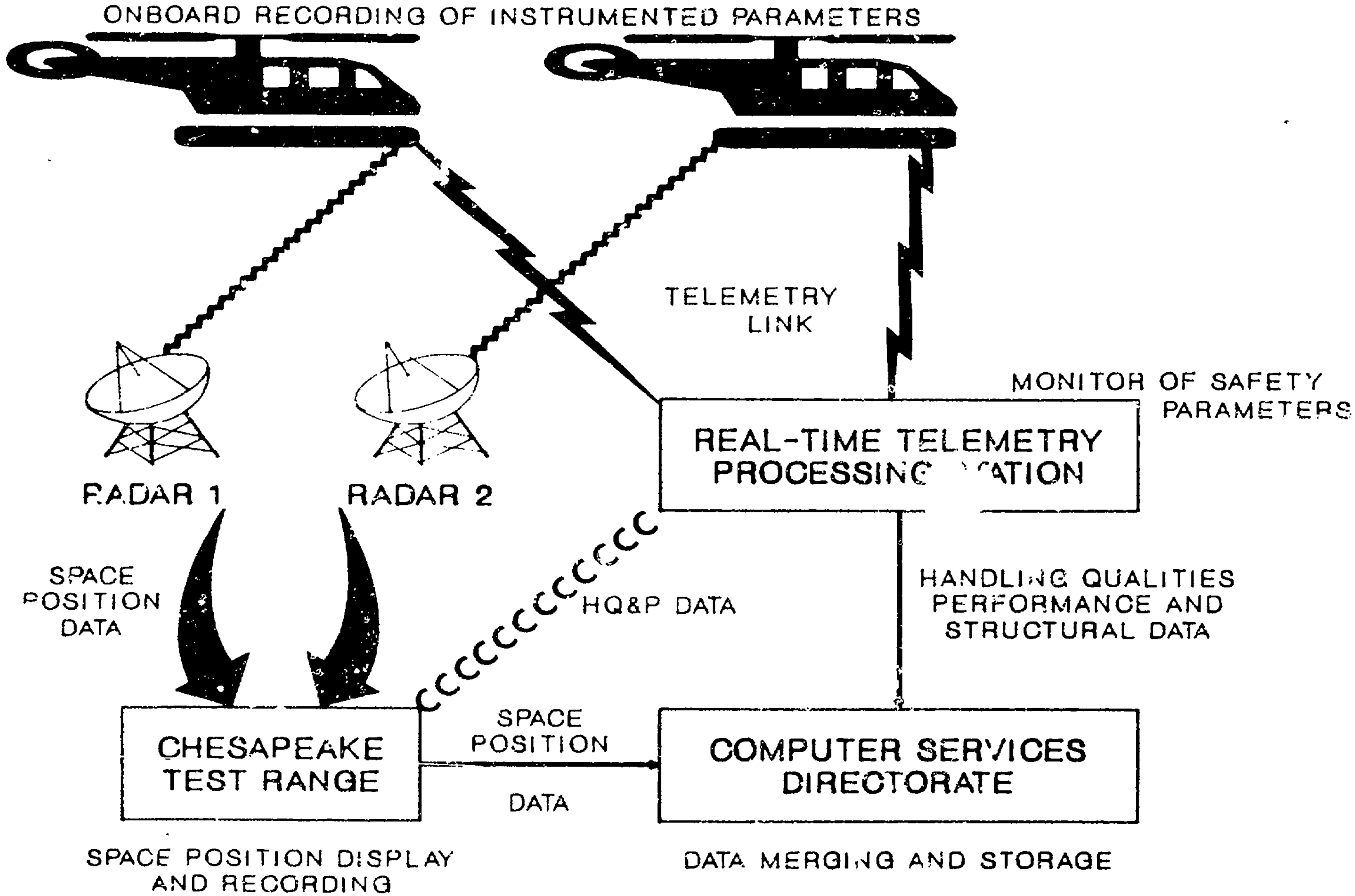


Figure 10. AACT data collection network.

Figure 11. AH-64A Apache vs 406 Combat Scout.

Figure 12. AH-64A Apache vs SA-365N-1 Dauphin.

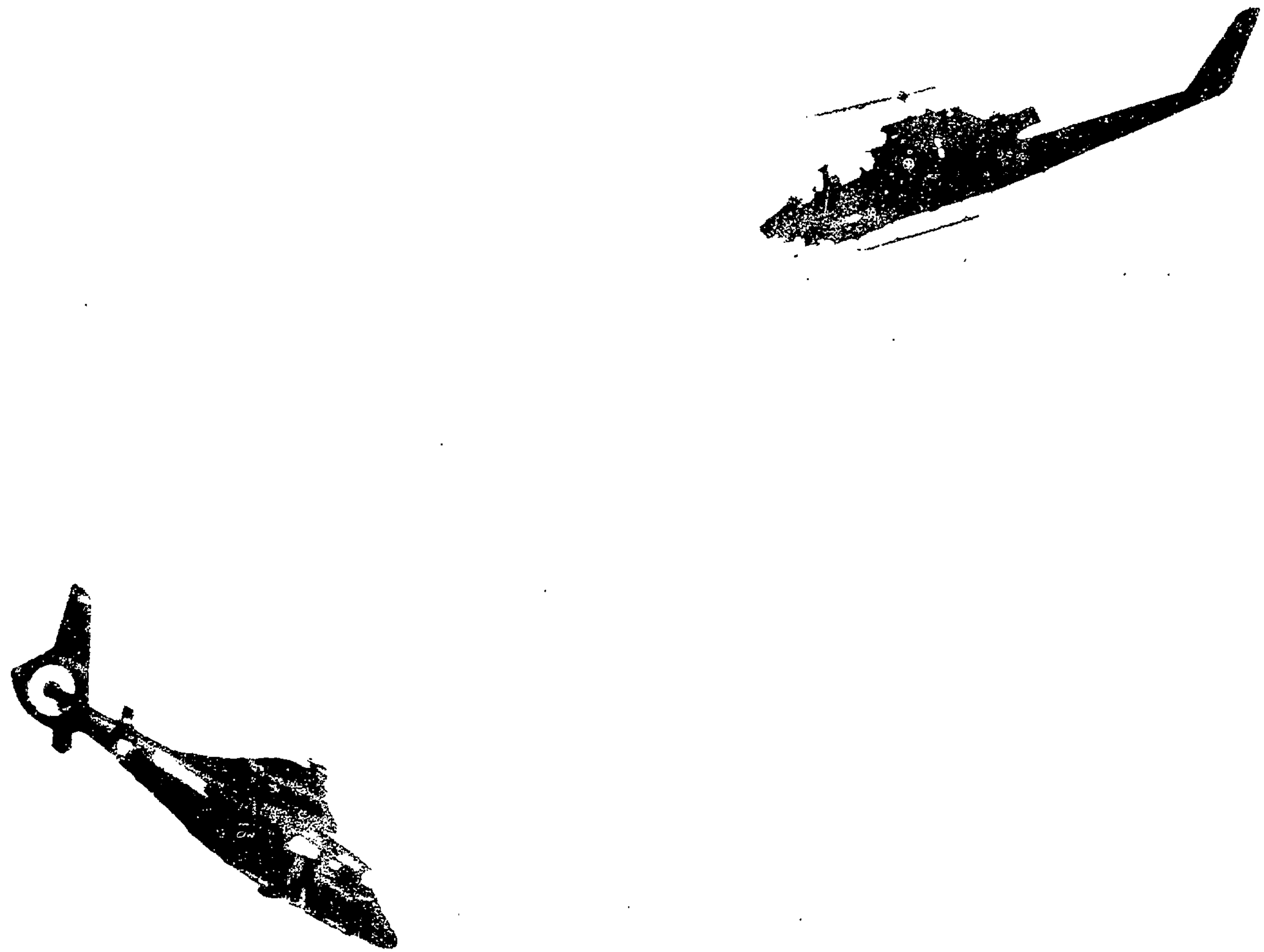


Figure 13. SA-365N-1 Dauphin vs AH-1S Cobra.

Figure 14. SA-365N-1 Dauphin vs 406 Combat Scout.

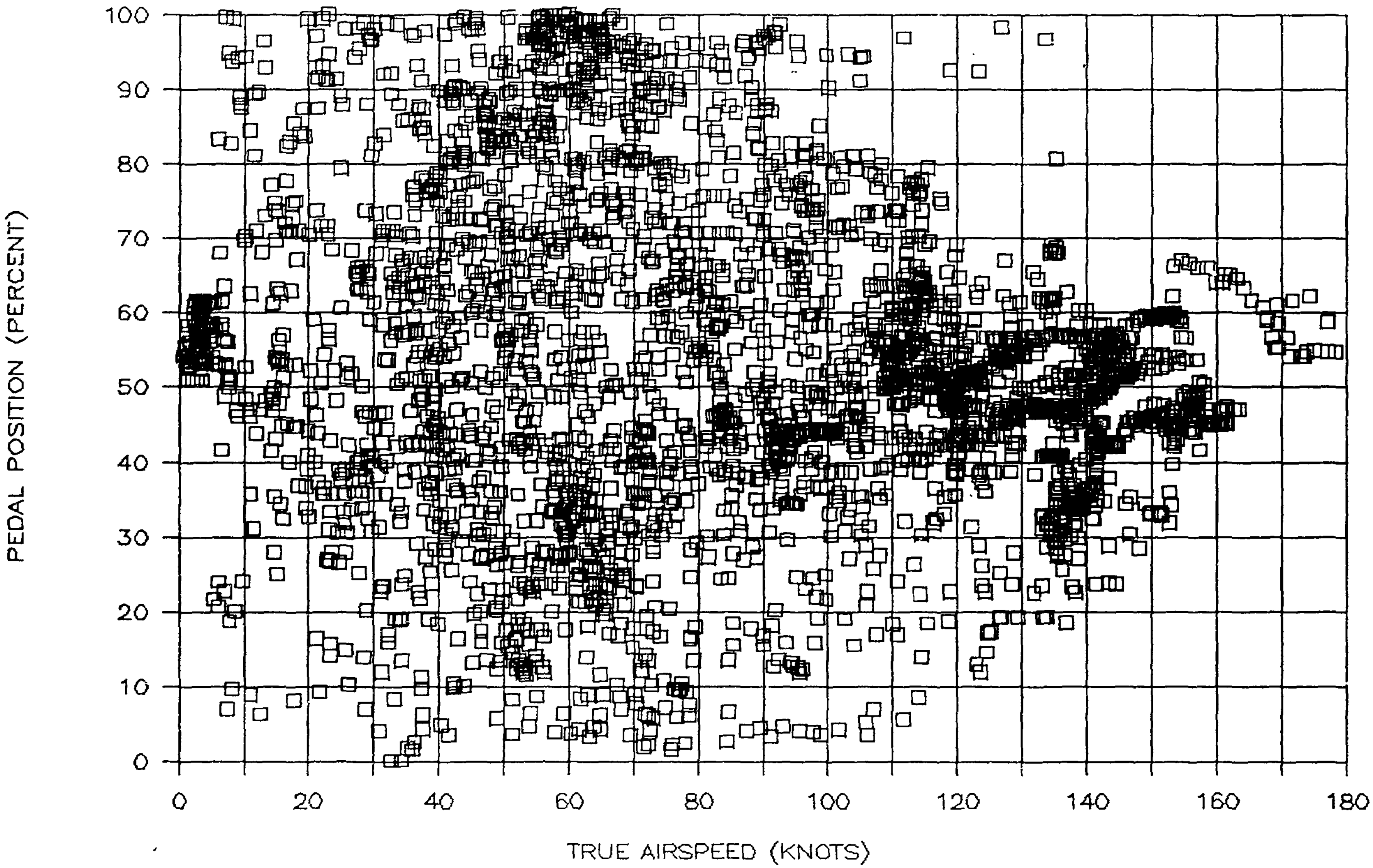
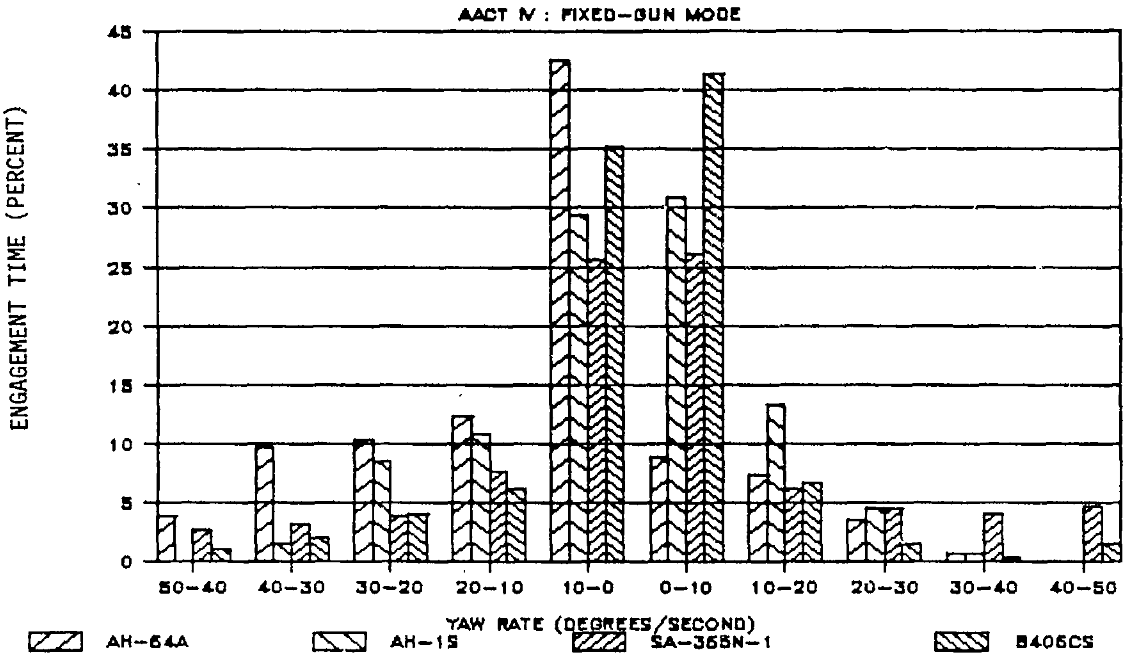


Figure 15. SA-365N-1 pedal position vs airspeed.



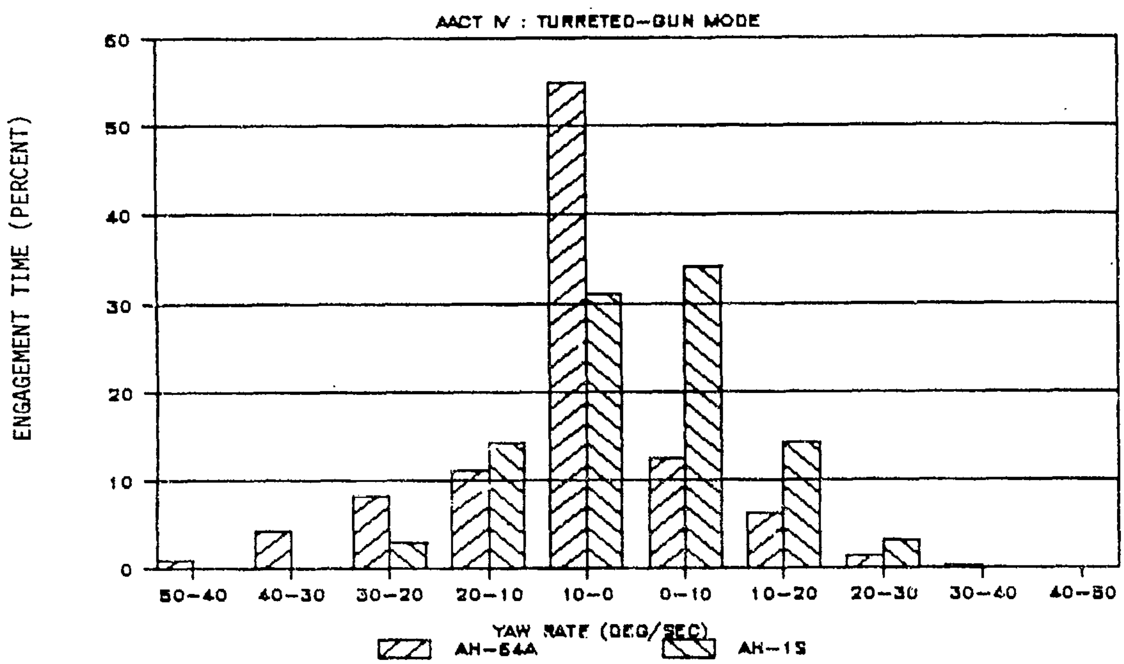
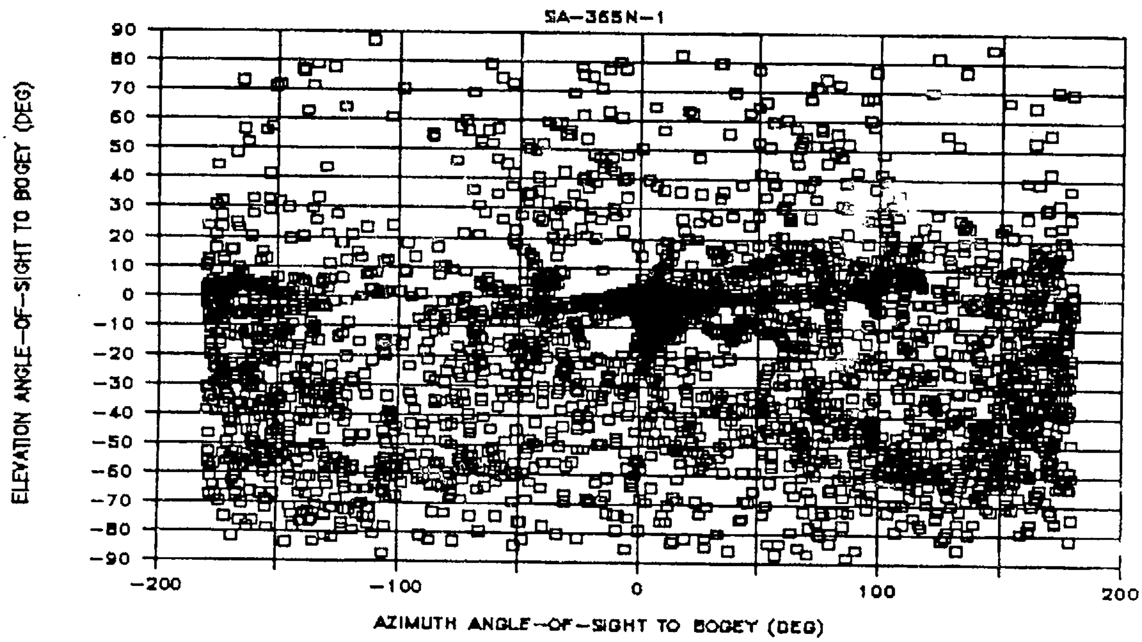


Figure 16. Yaw rate histograms - fixed and turreted gun modes.



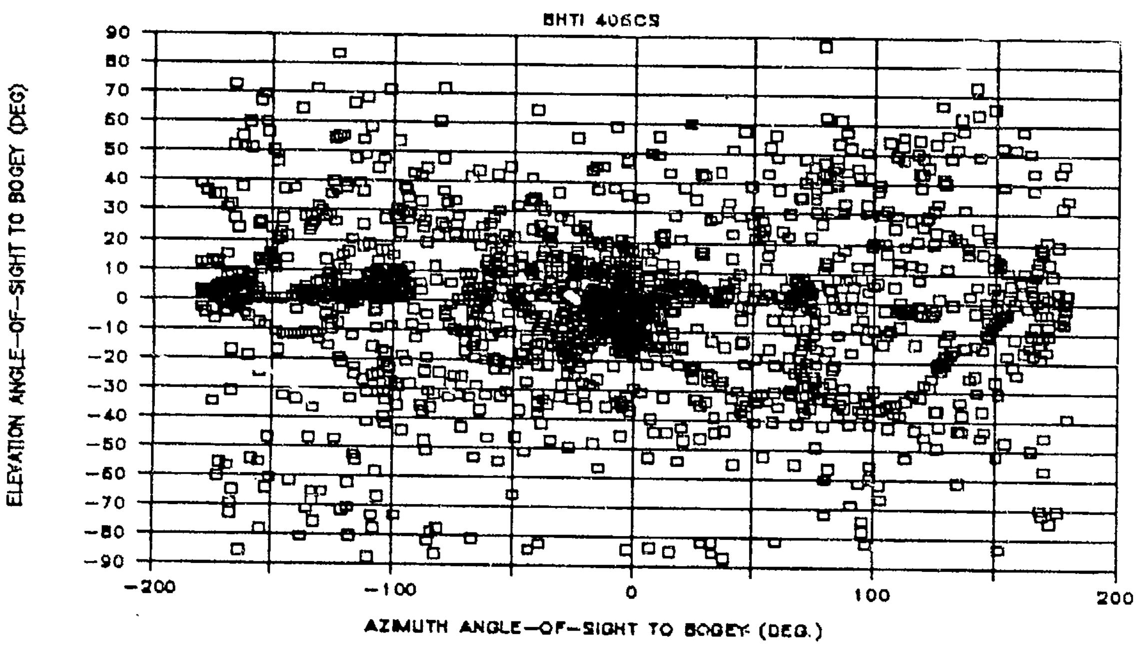
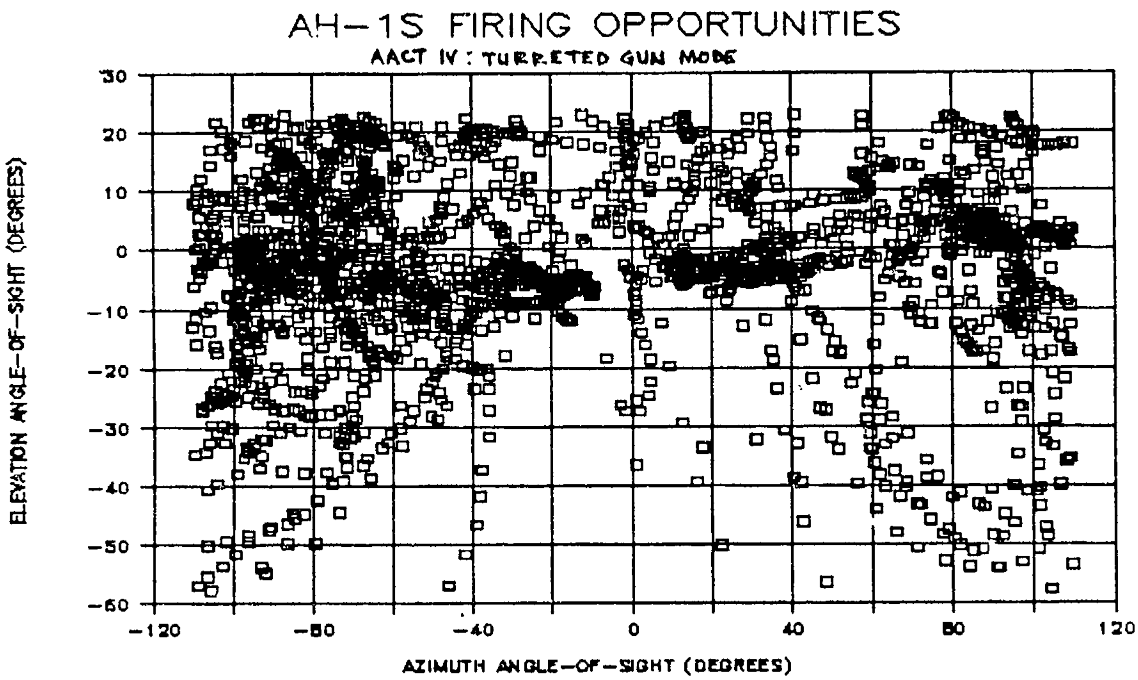


Figure 17. Angle-of-sight to bogey - fixed gun.



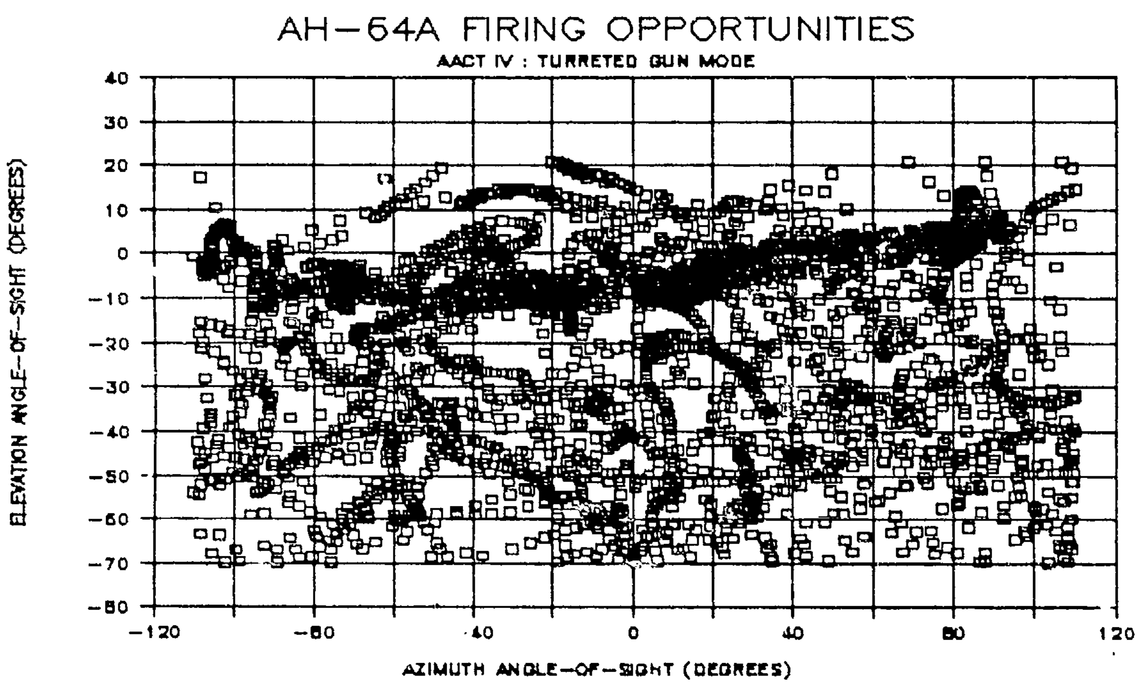


Figure 18. Turret window angle-of-sight to bogey.

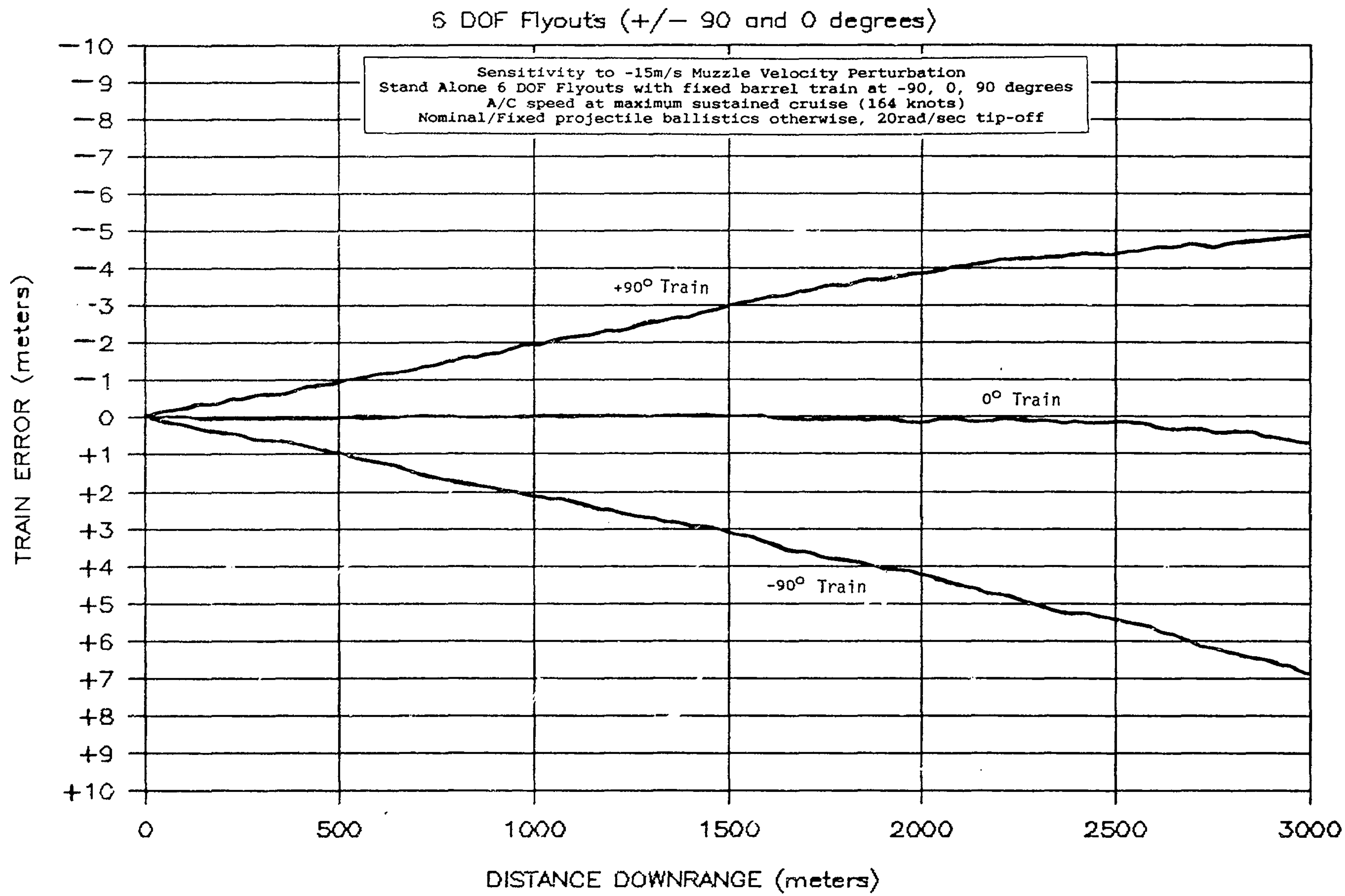


Figure 19. Side/forward firing comparison of train errors vs range.

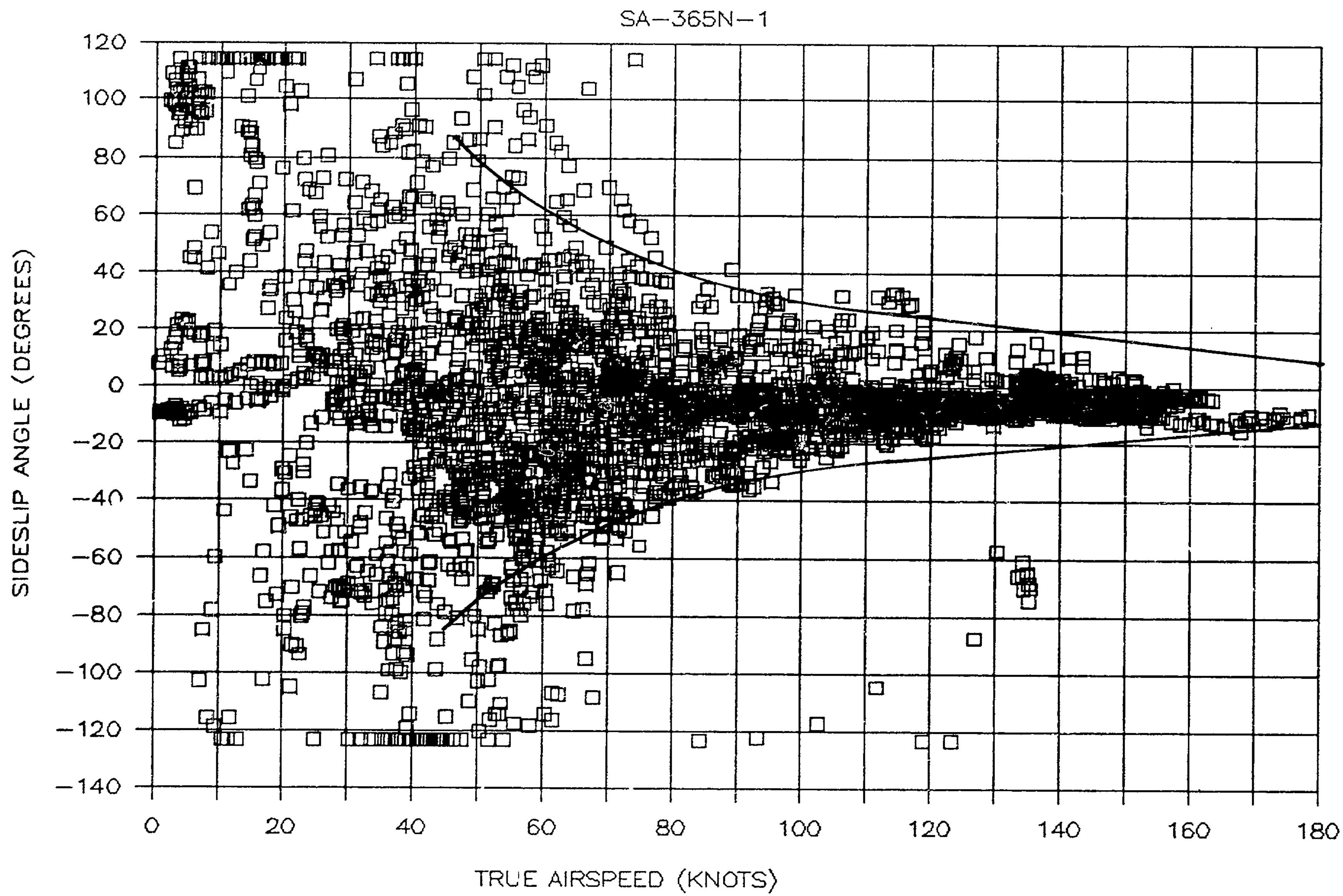


Figure 20. Sideslip angle vs airspeed.

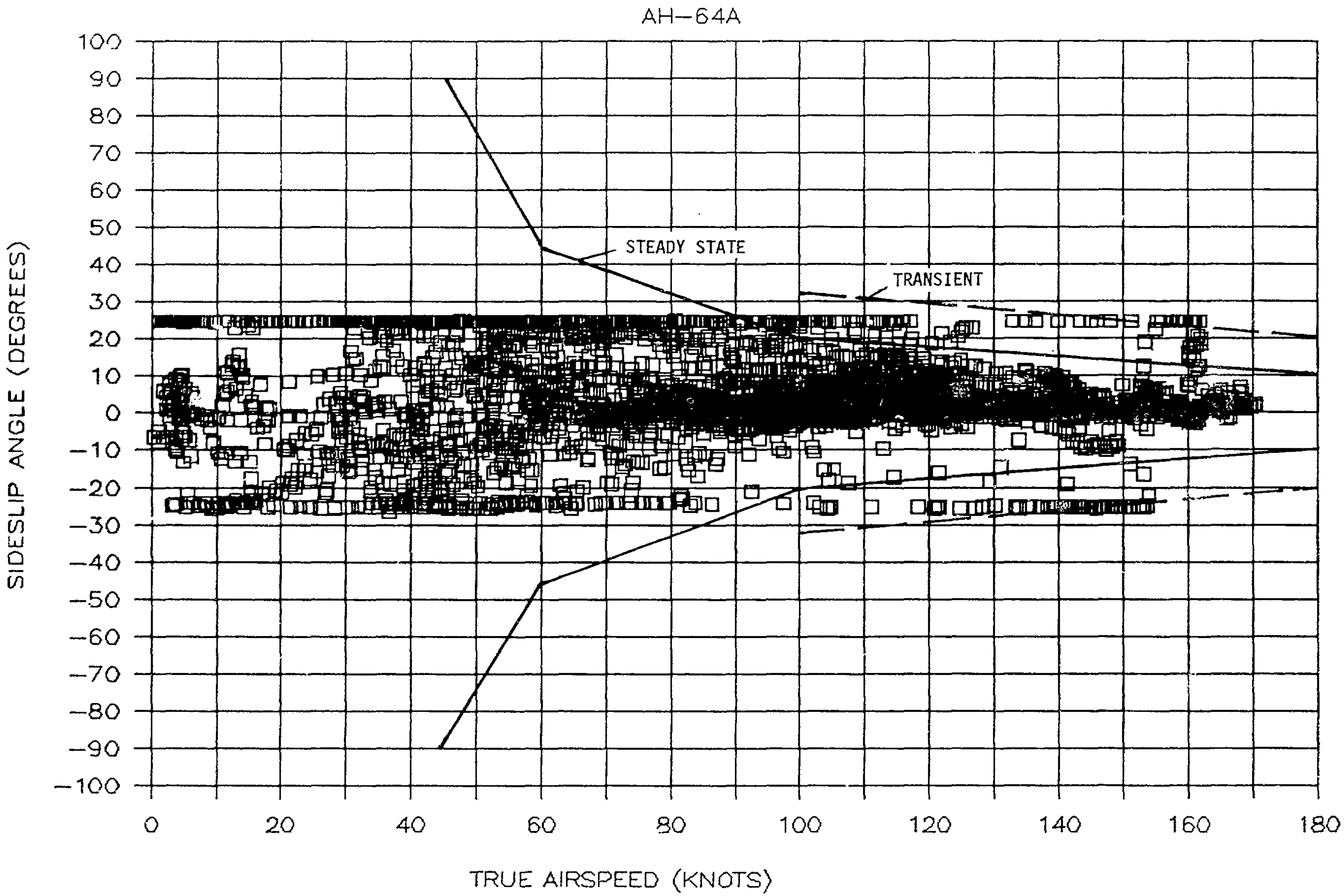


Figure 20. Sideslip angle vs airspeed. (Continued)

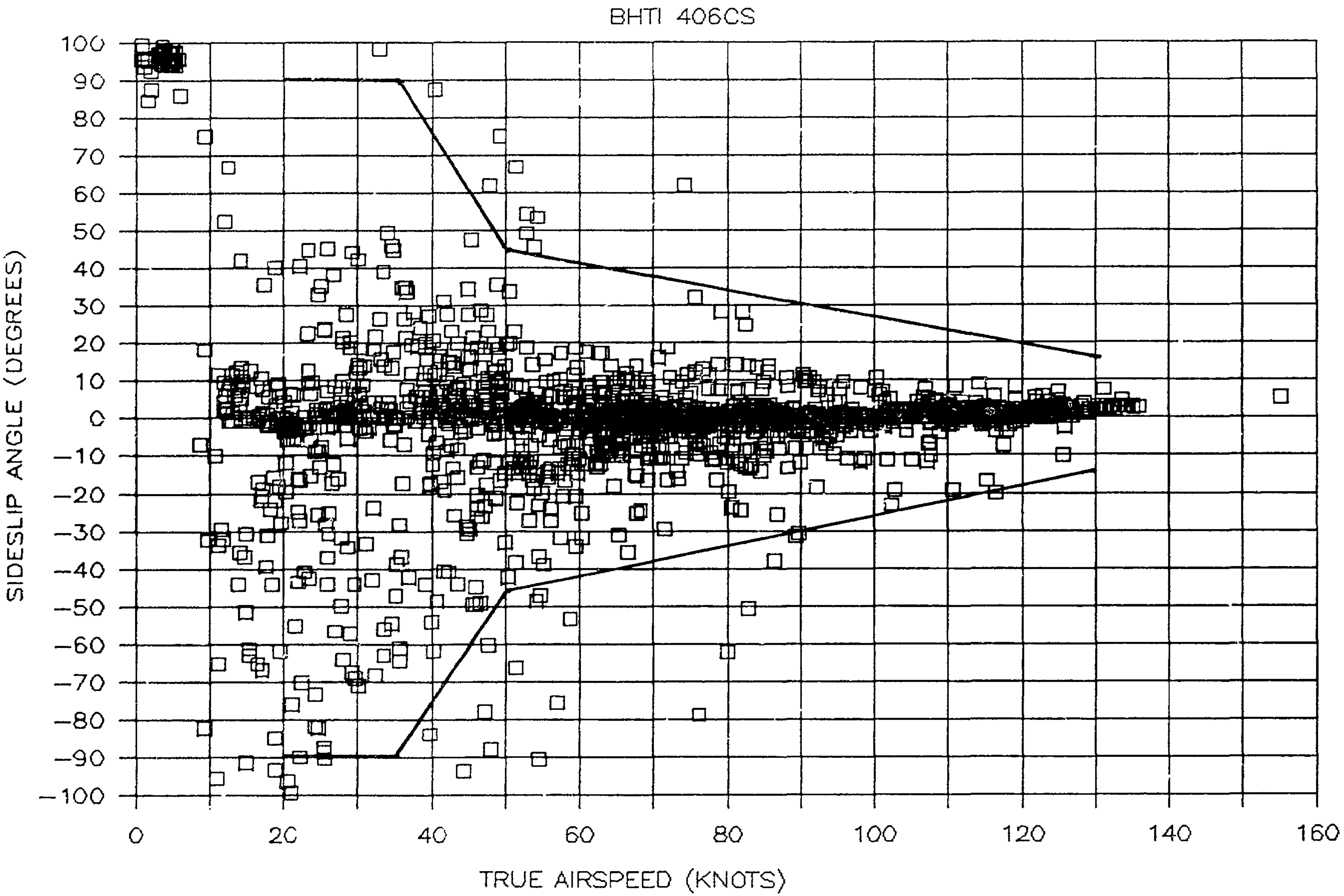


Figure 20. Sideslip angle vs airspeed. (Continued)

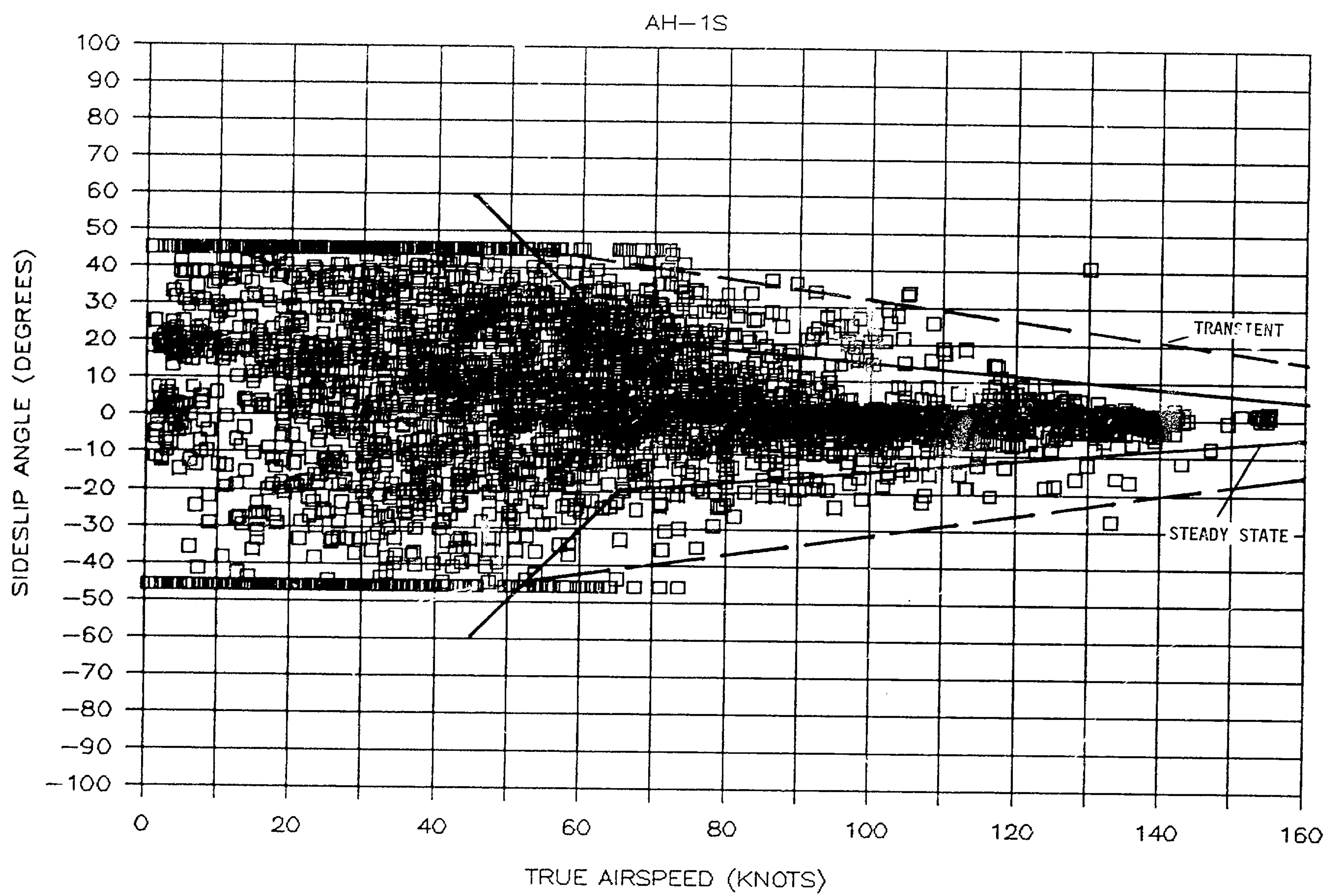


Figure 20. Sideslip angle vs airspeed. (Concluded)

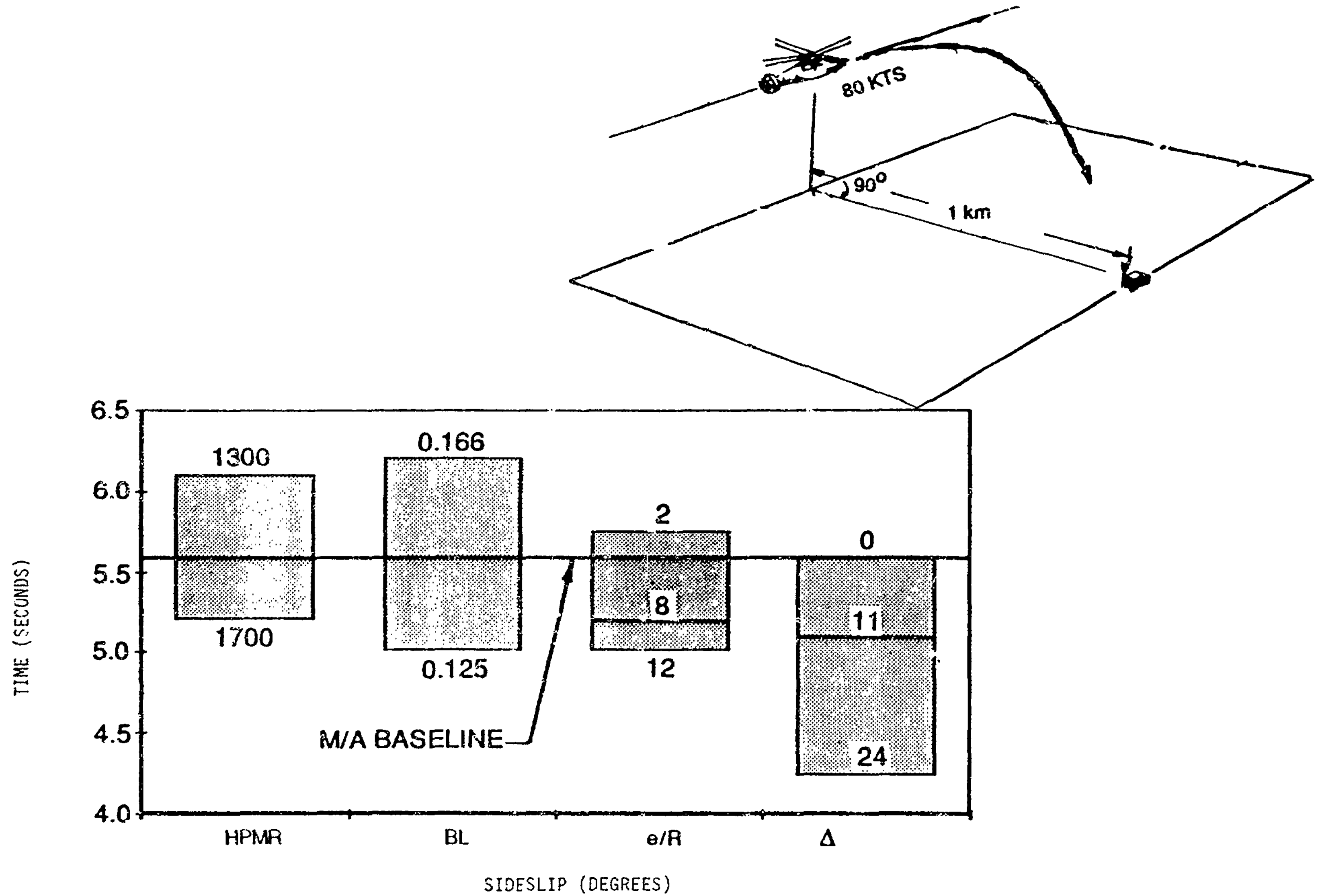
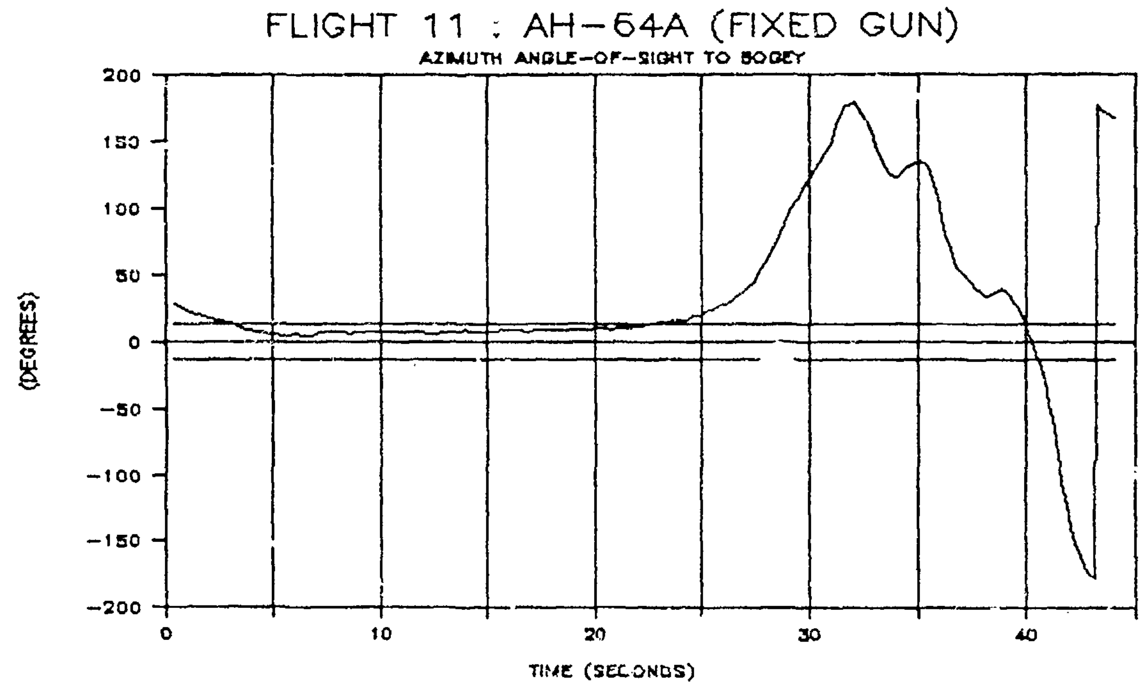


Figure 21. Time to turn on target - 80-knot steady turn.



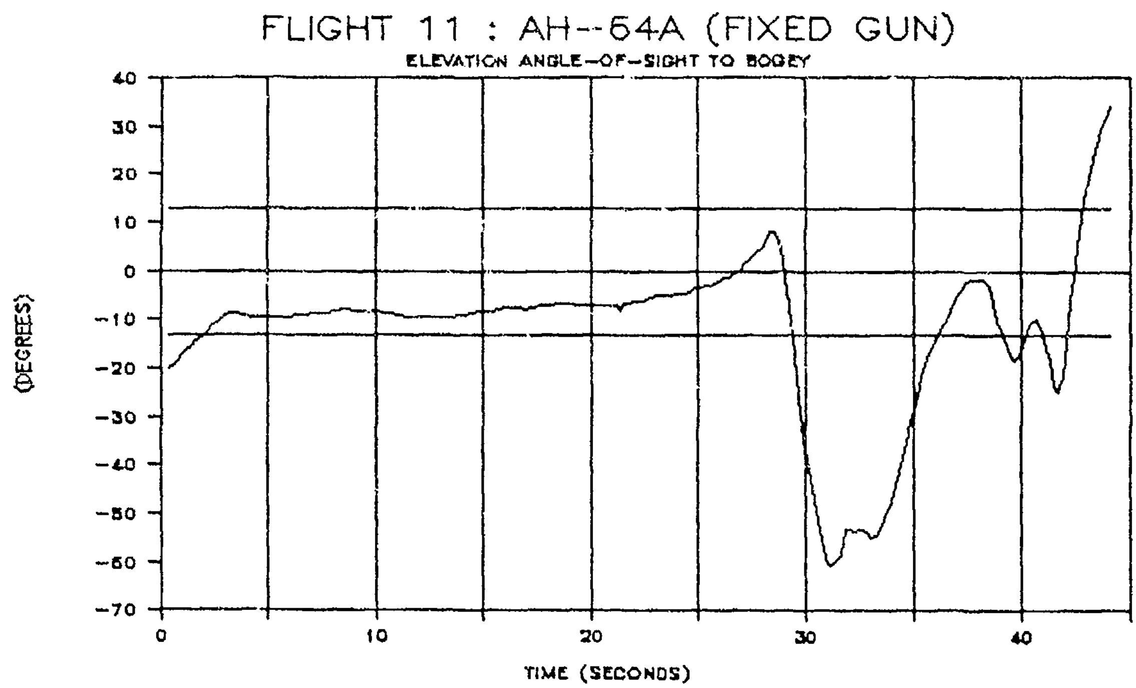
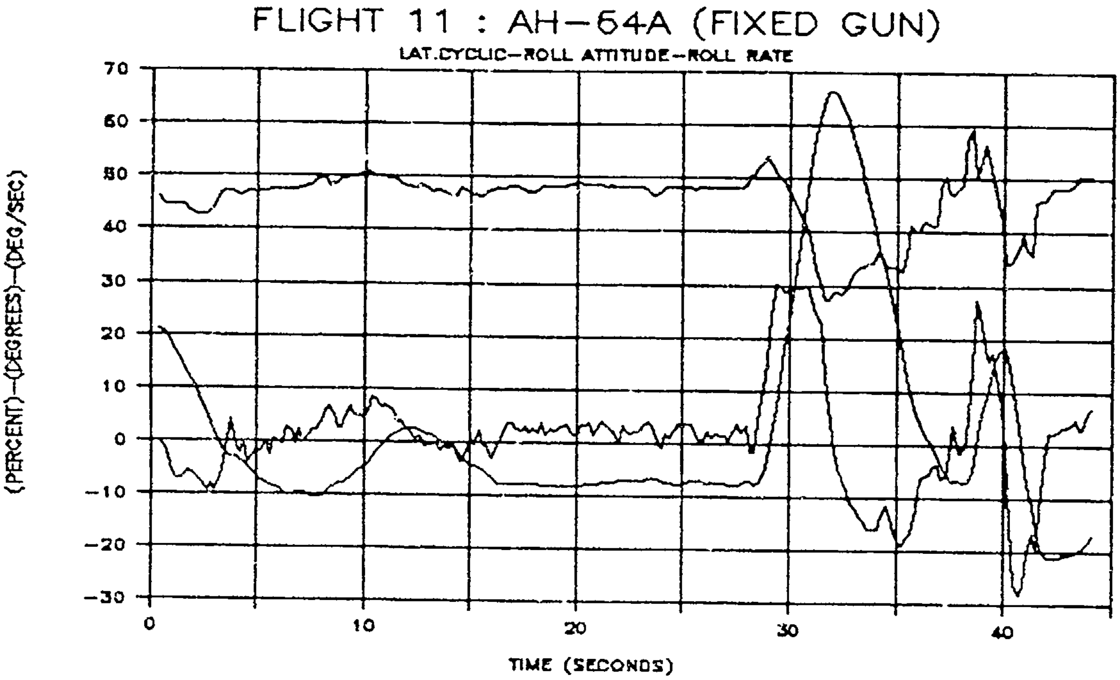


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1.



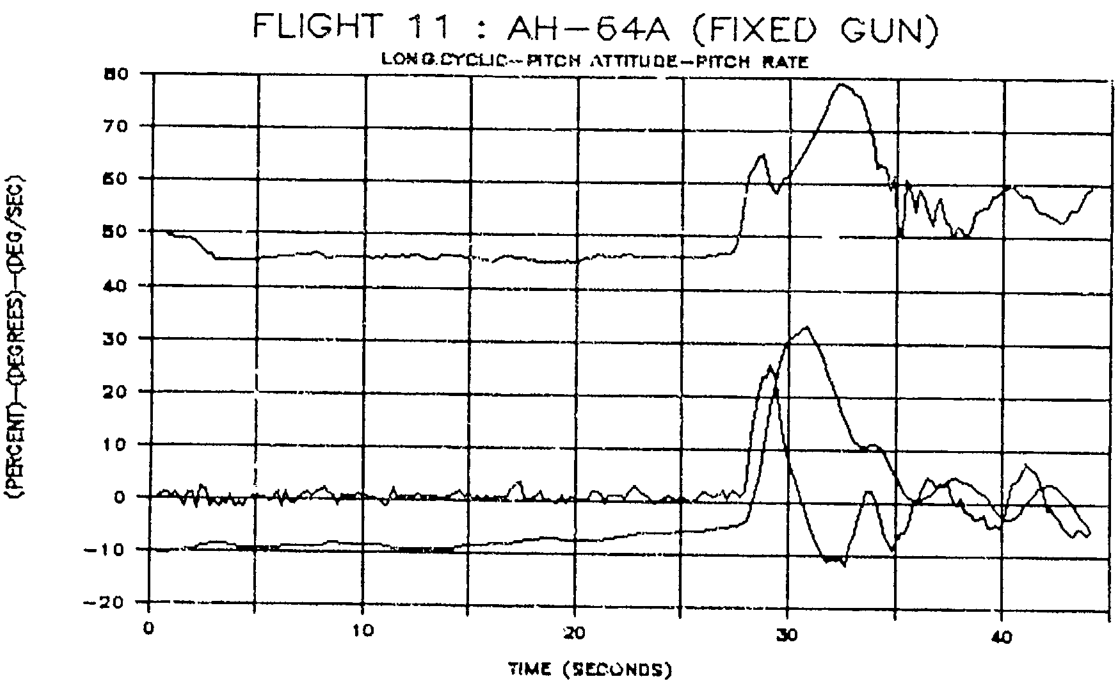


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)

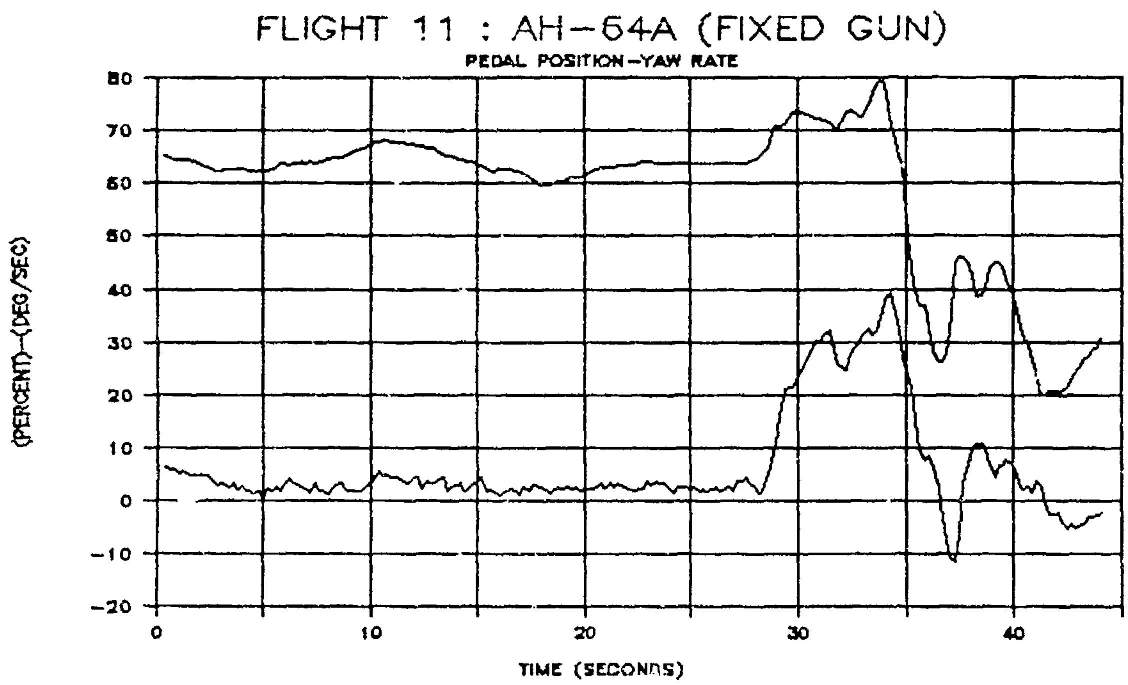
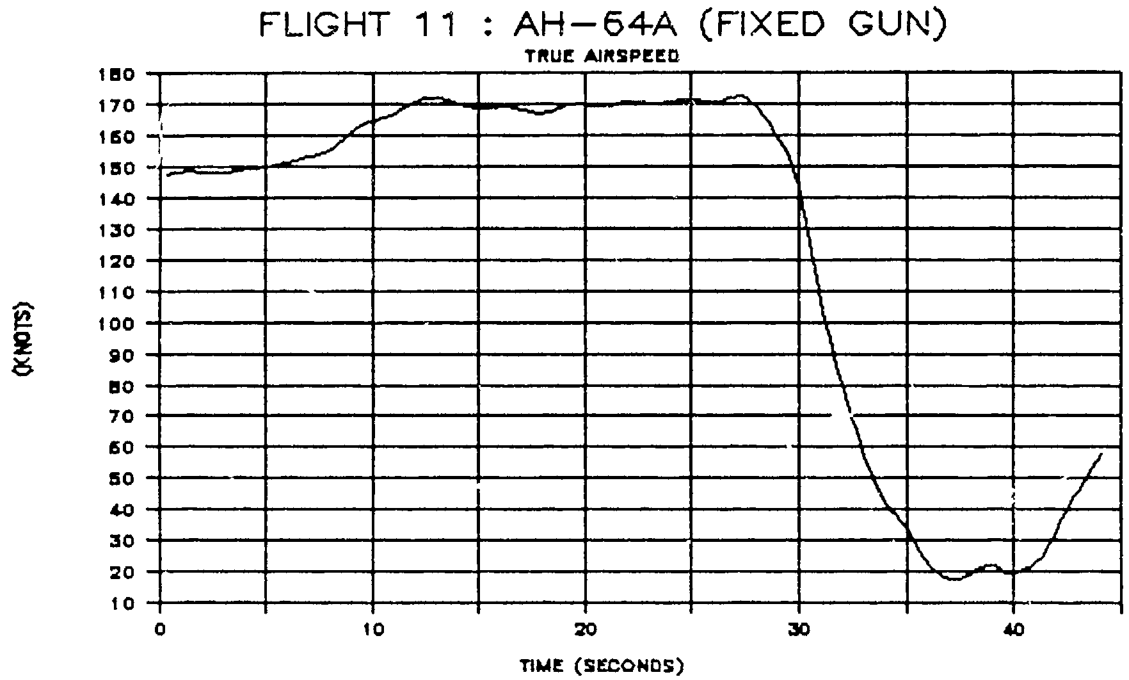


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)



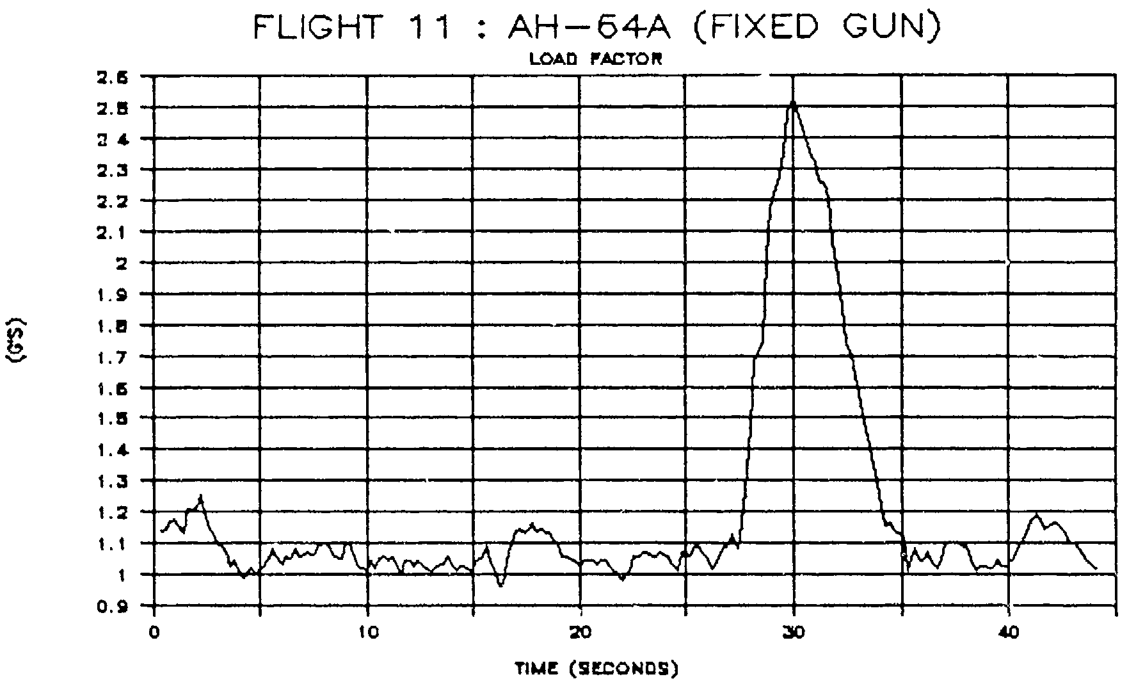
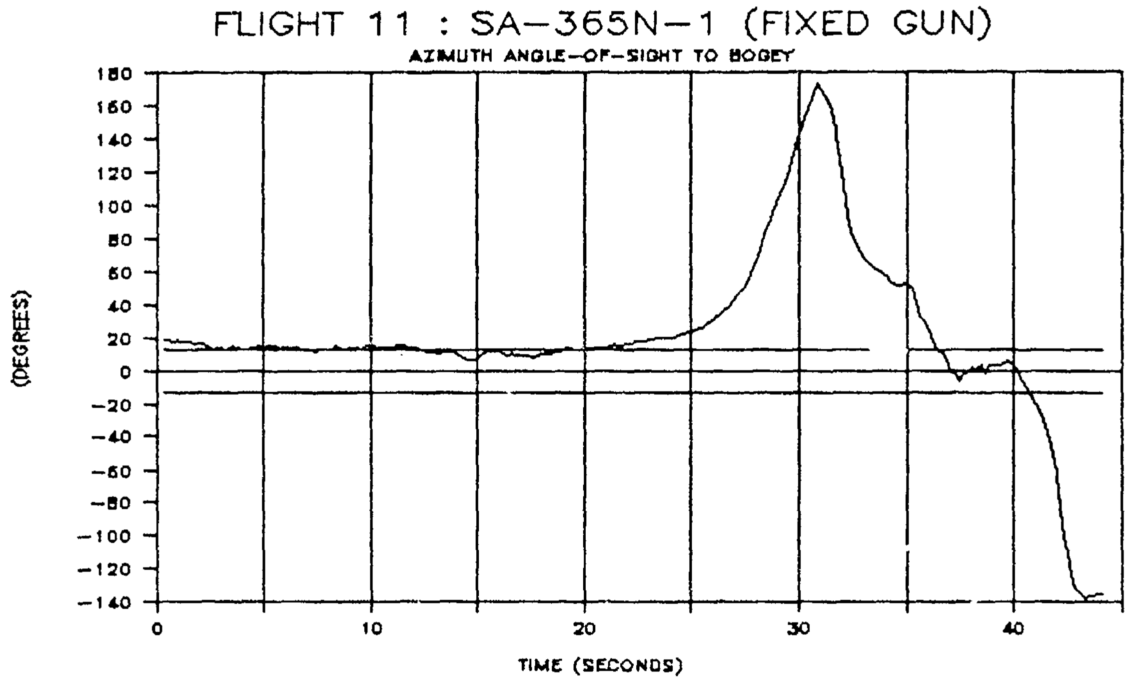


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)



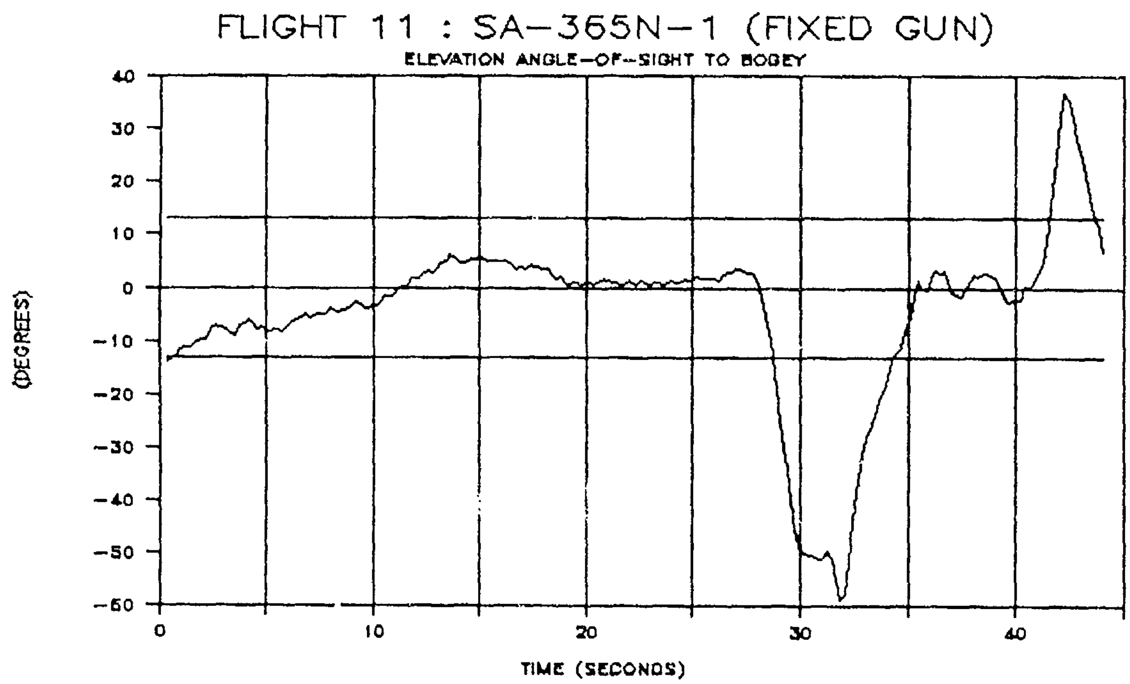
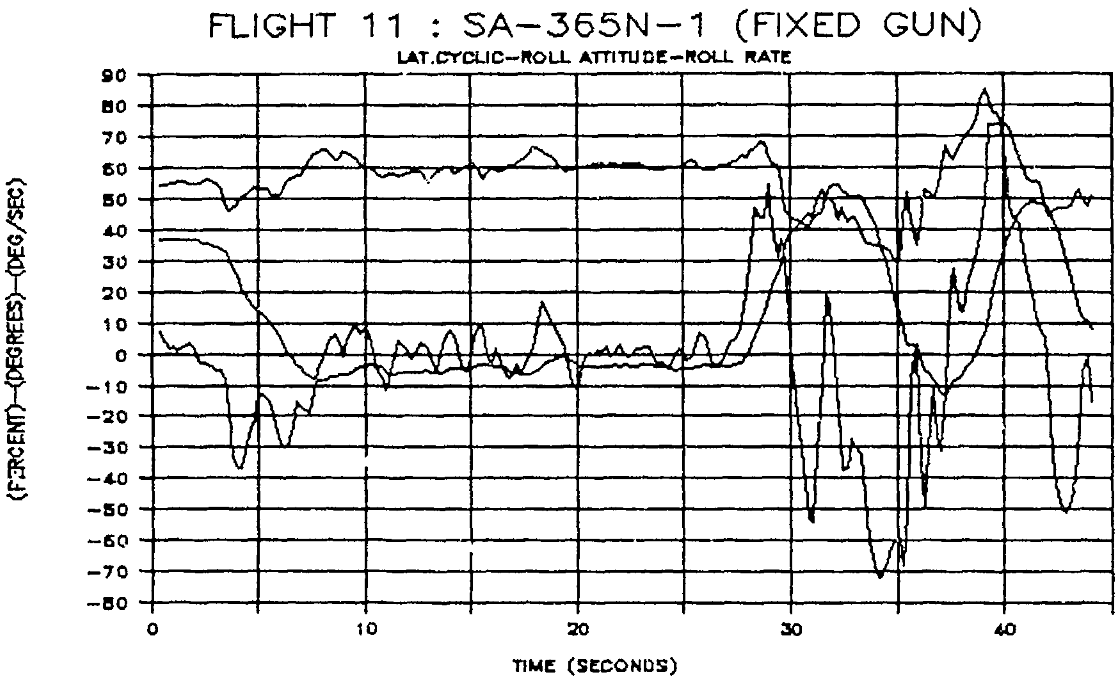


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)



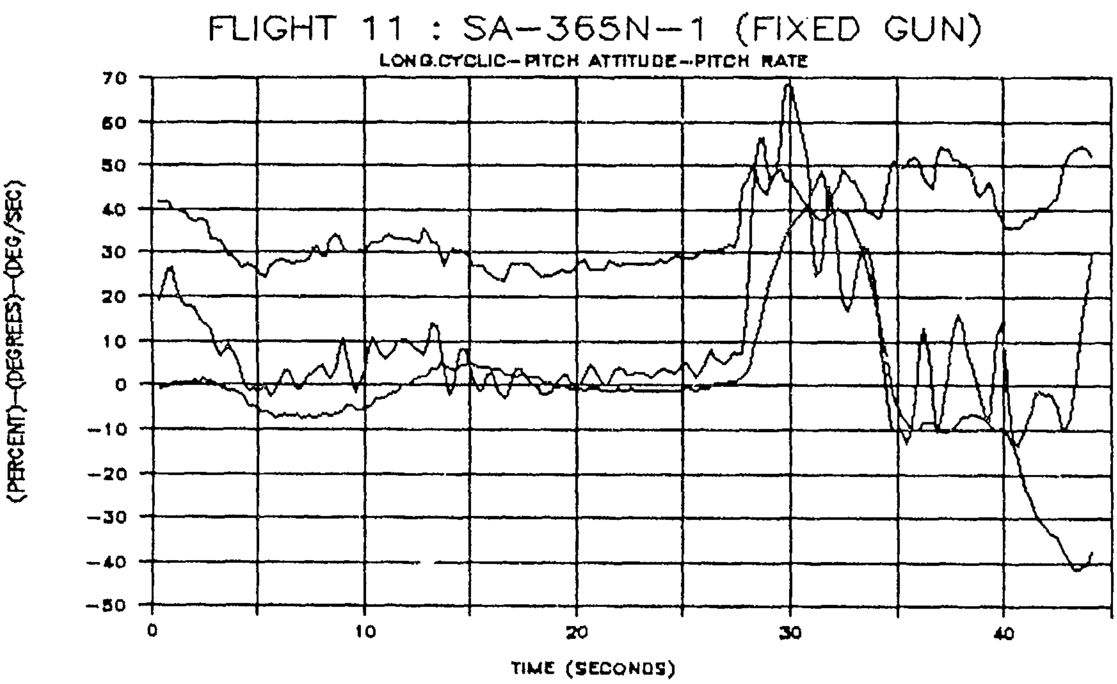


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)

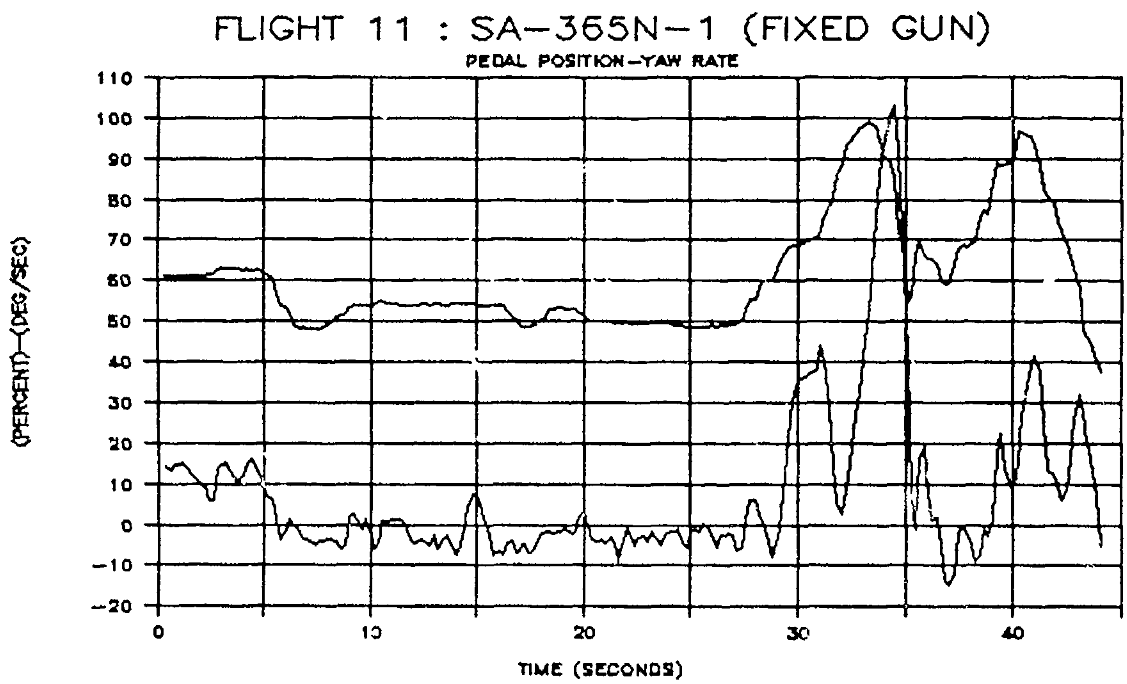
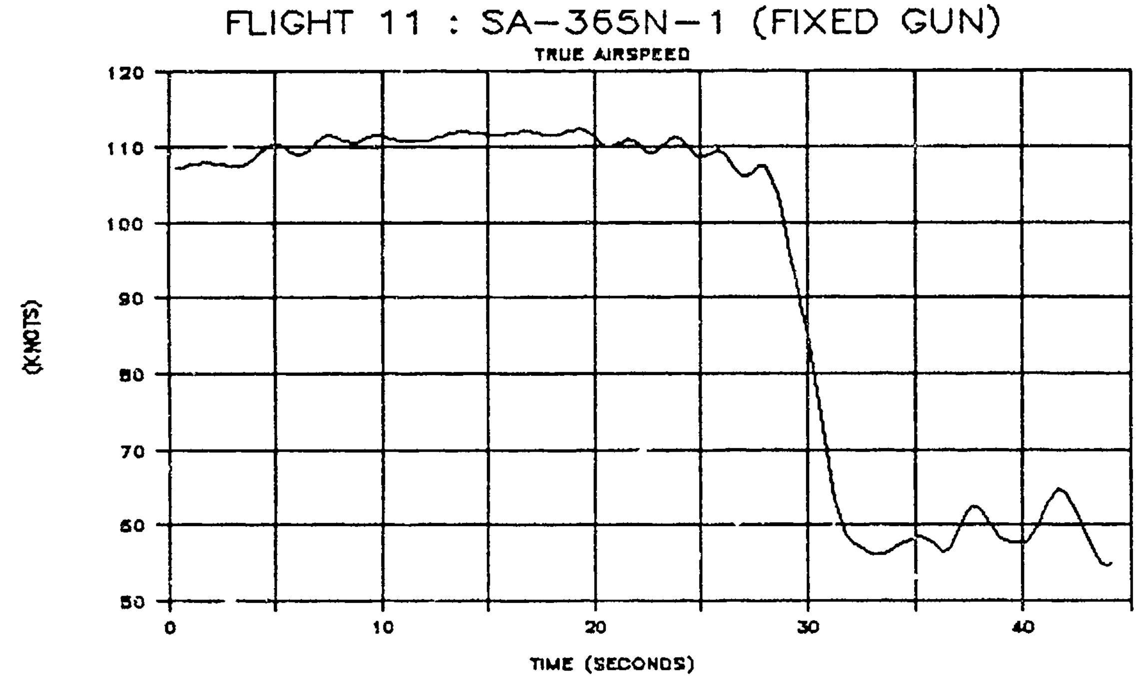


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Continued)



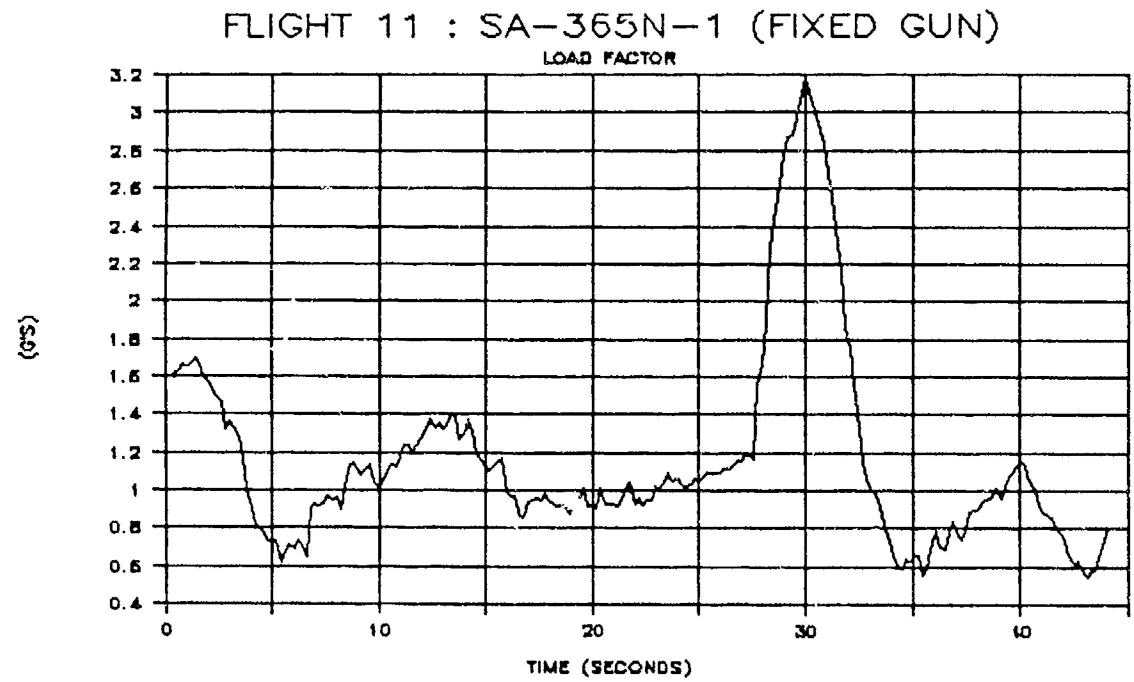
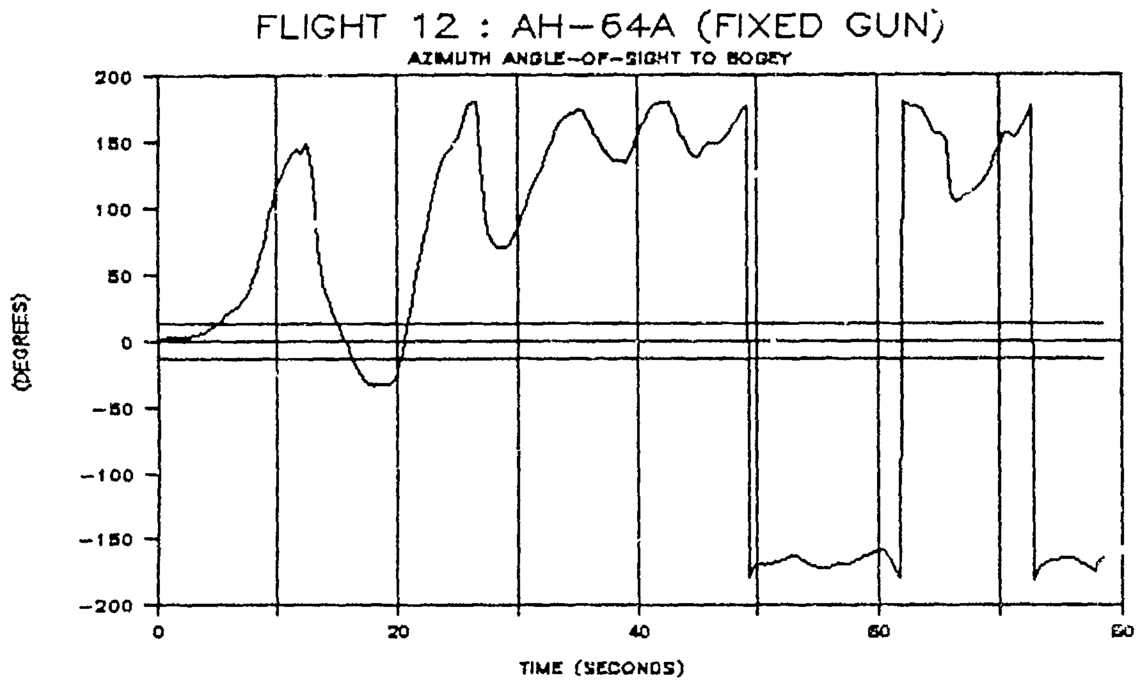


Figure 22. Head-to-head engagement time histories - AH-64A vs SA-365N-1. (Concluded)



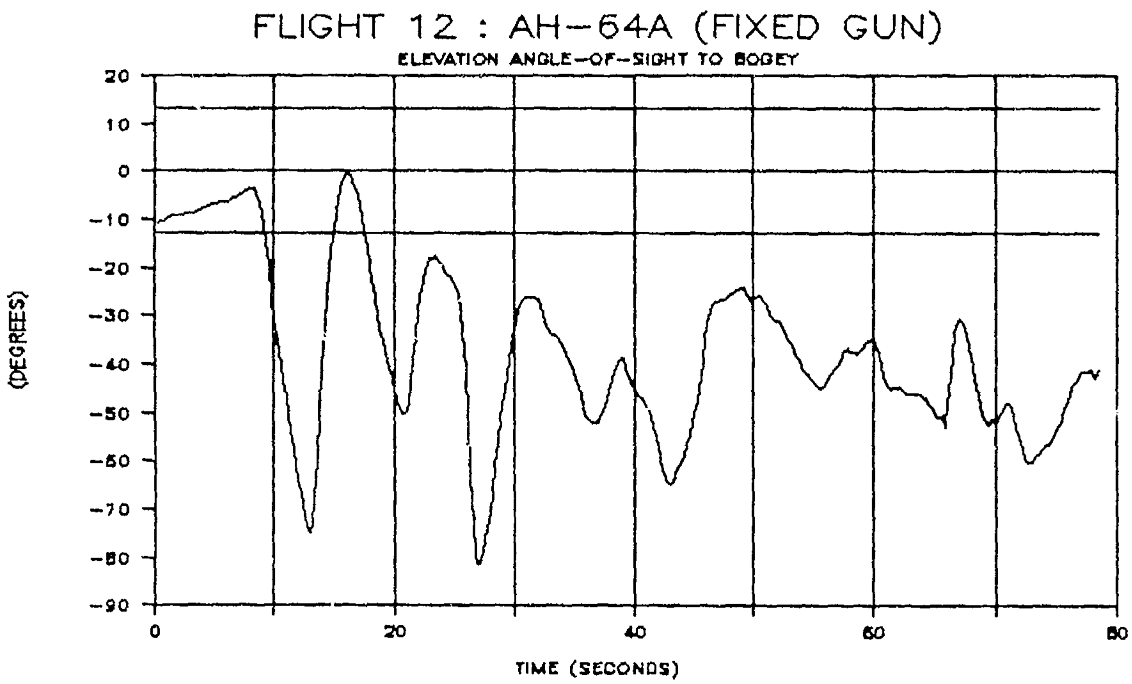
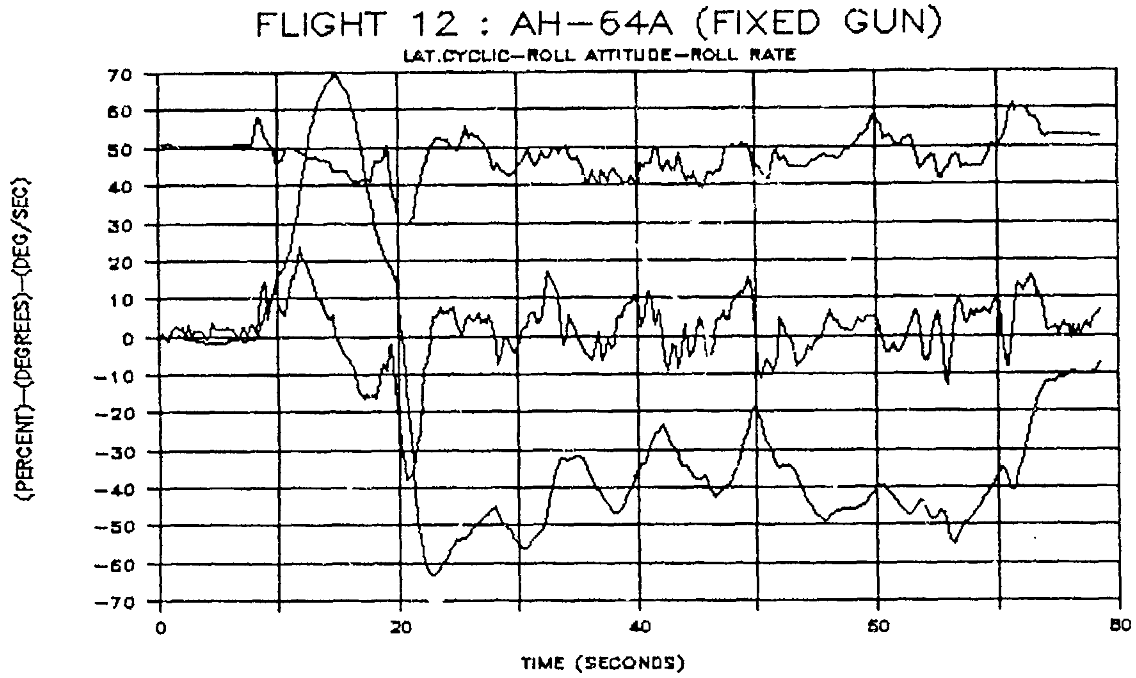


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S.



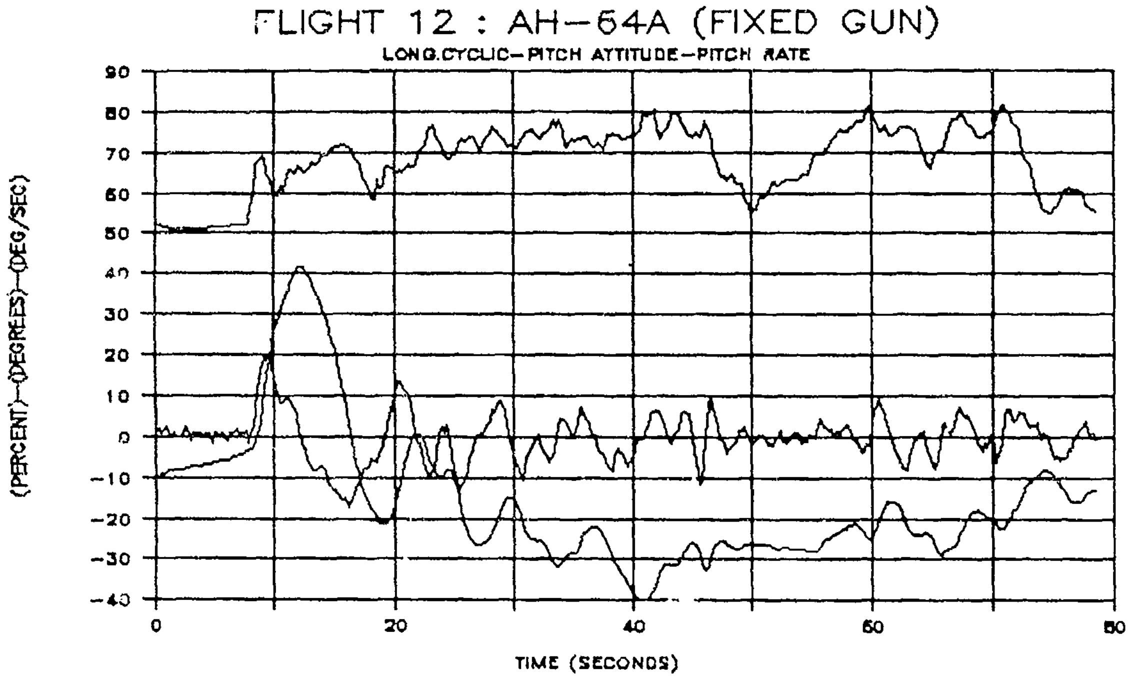


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)

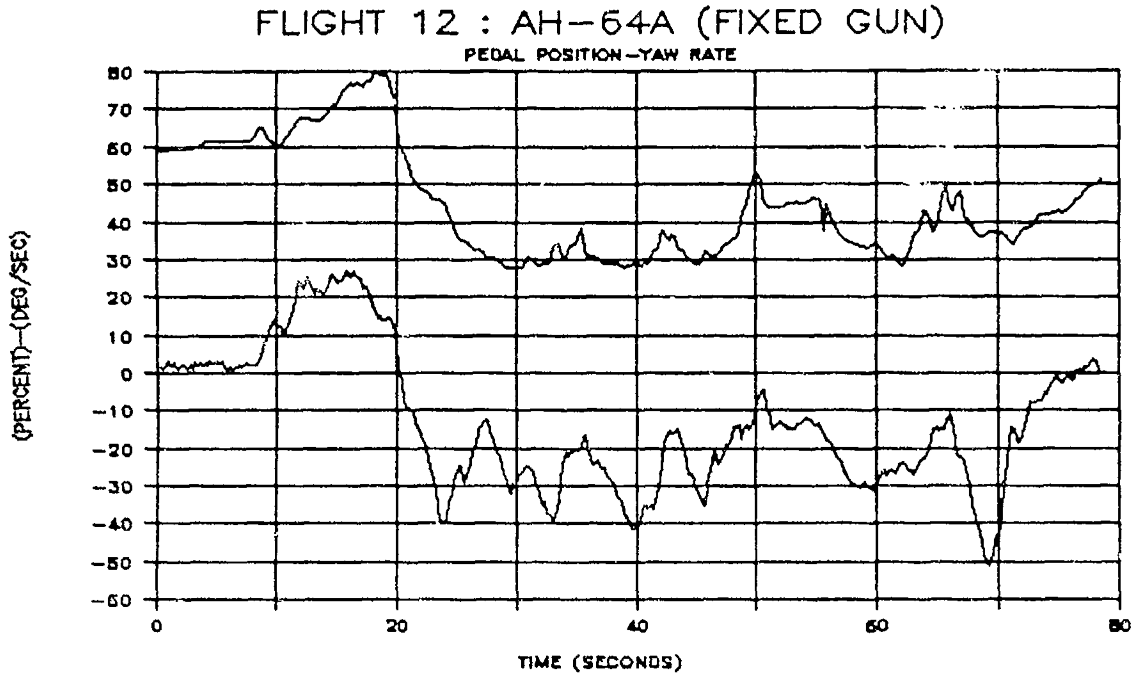
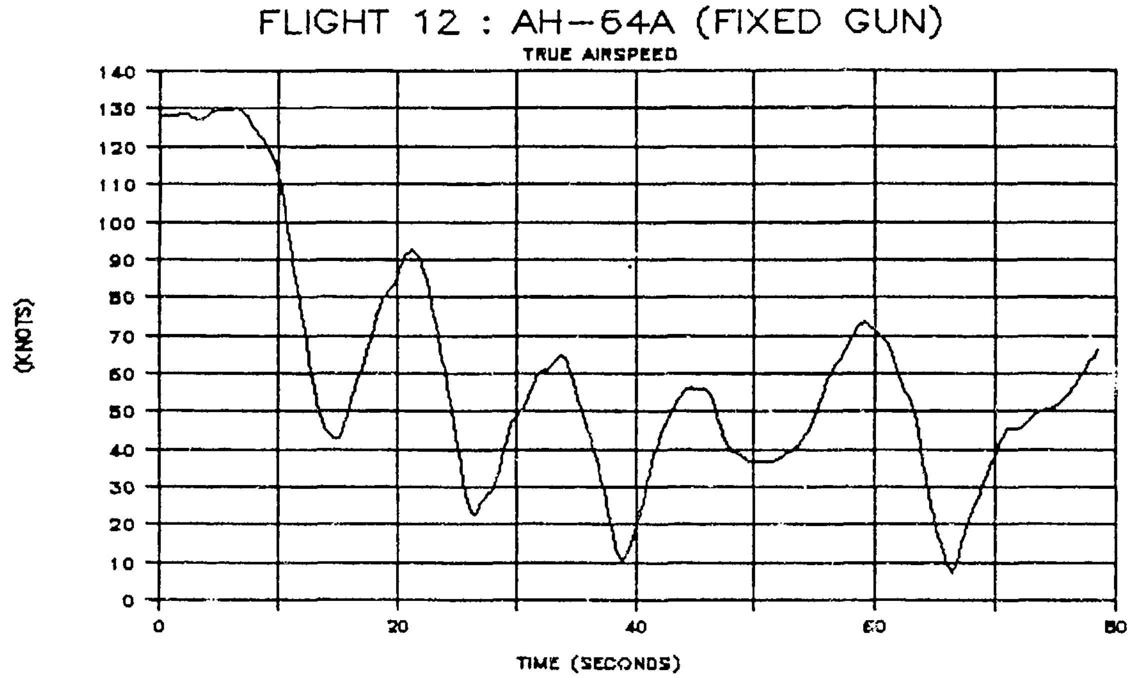


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)



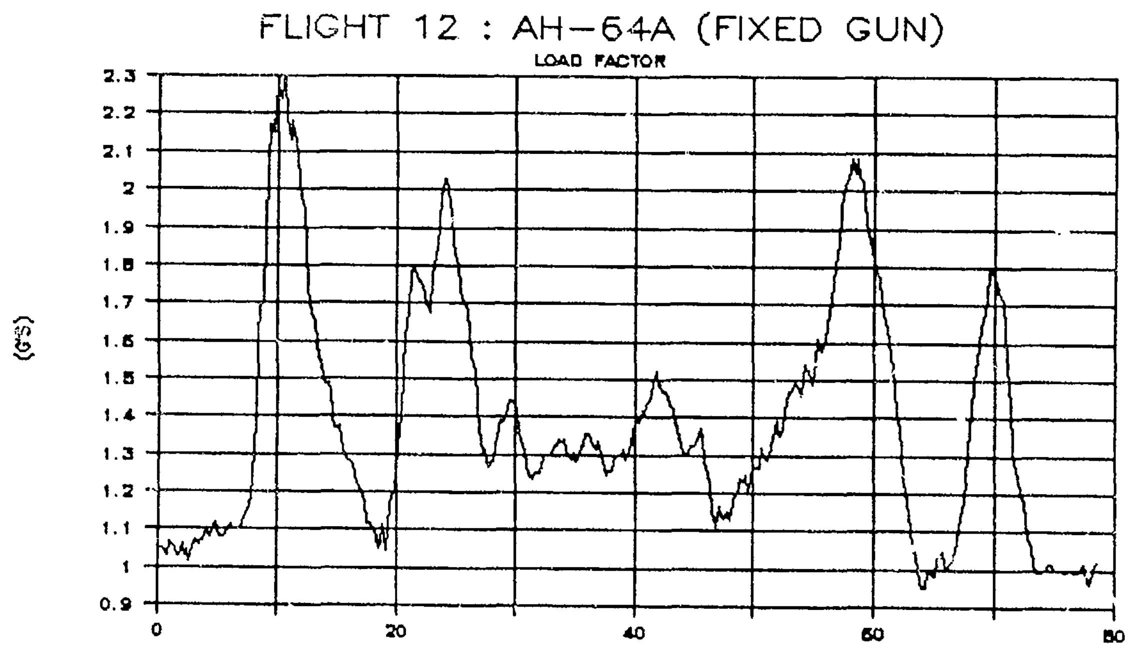
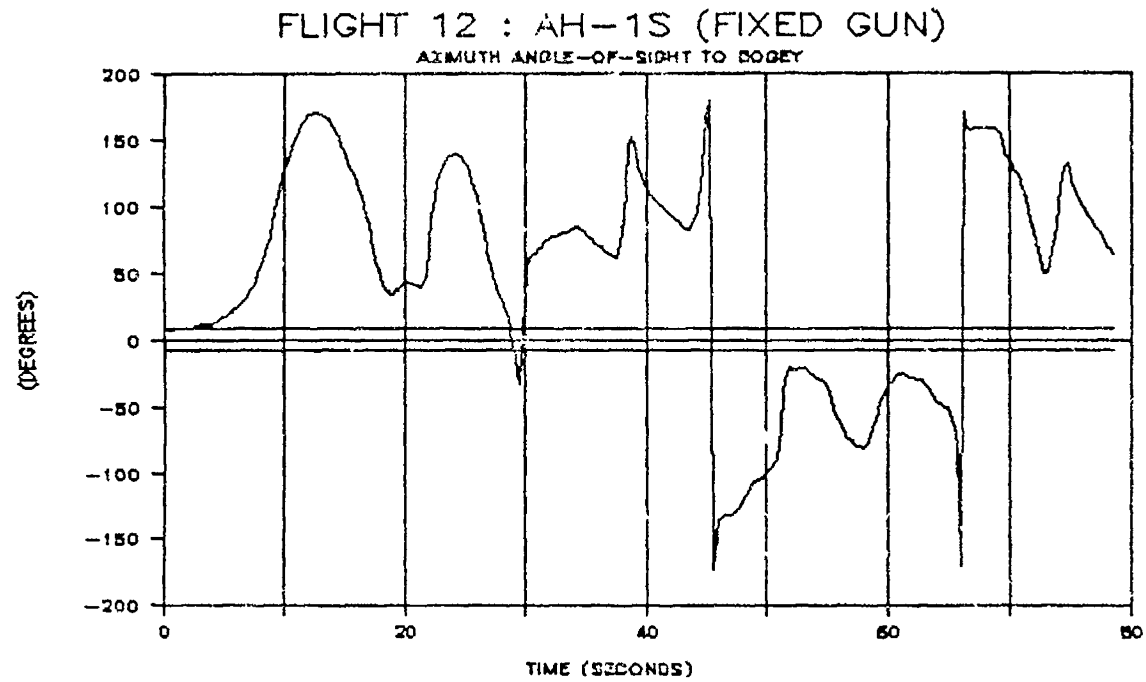


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)



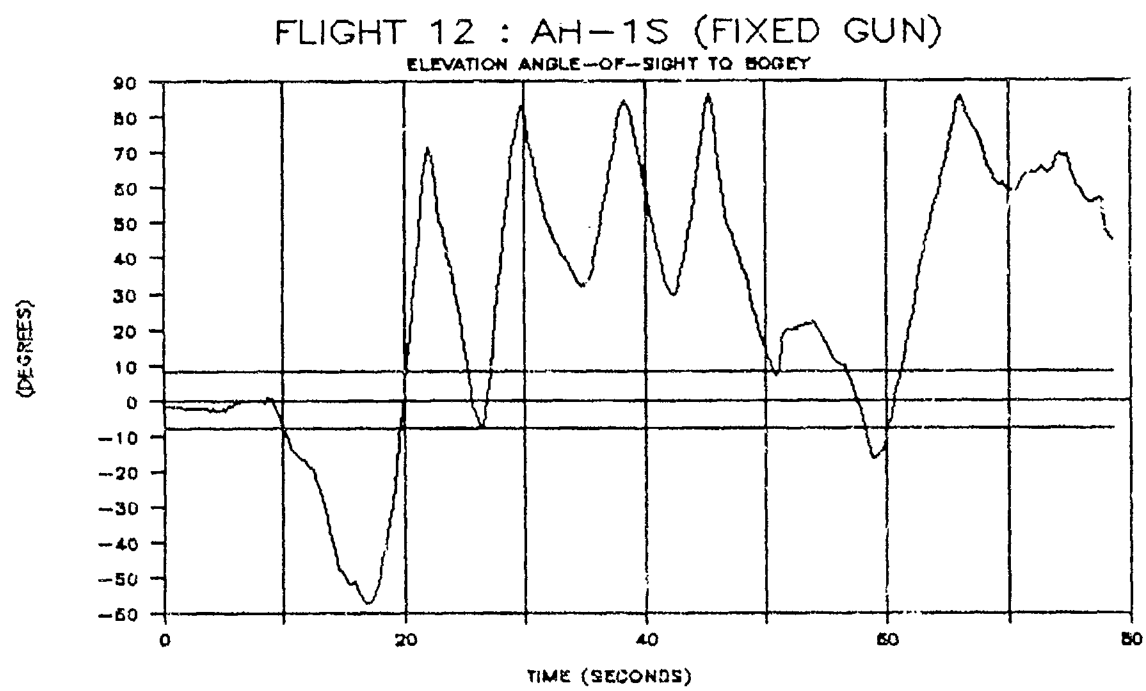
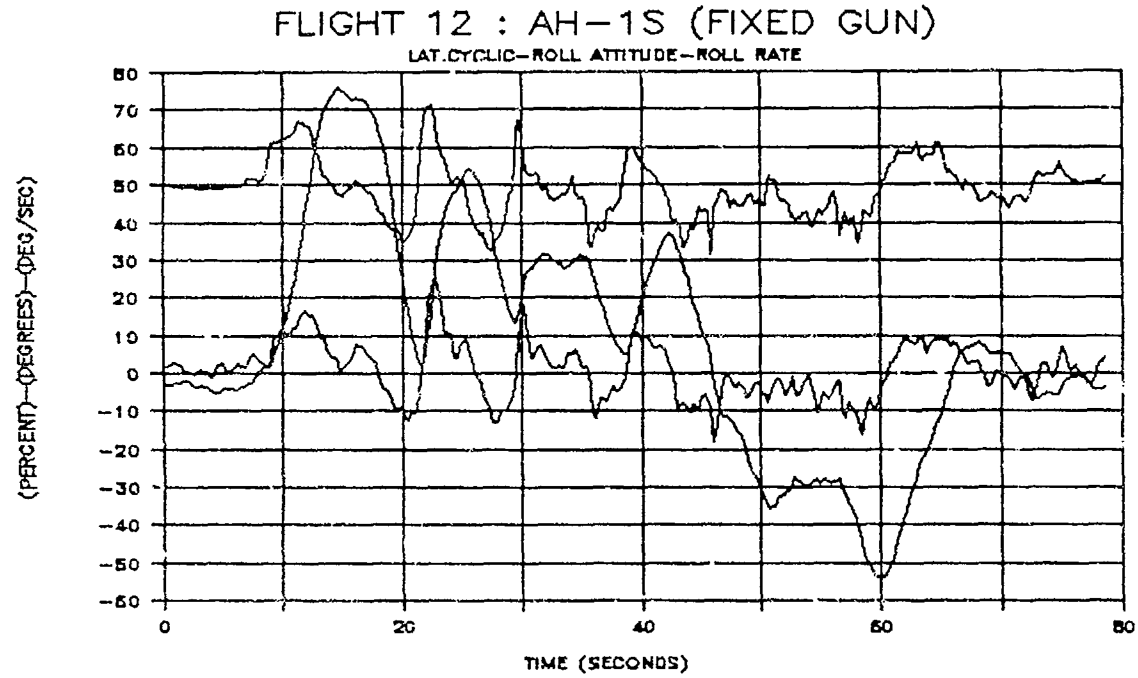


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)



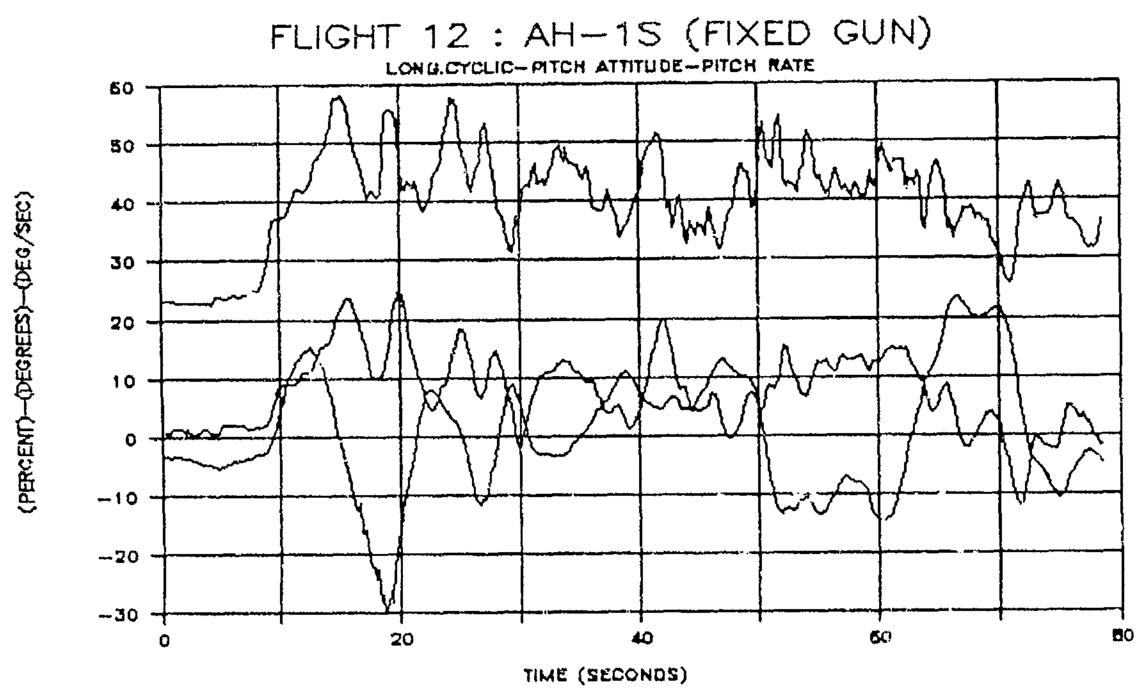


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)

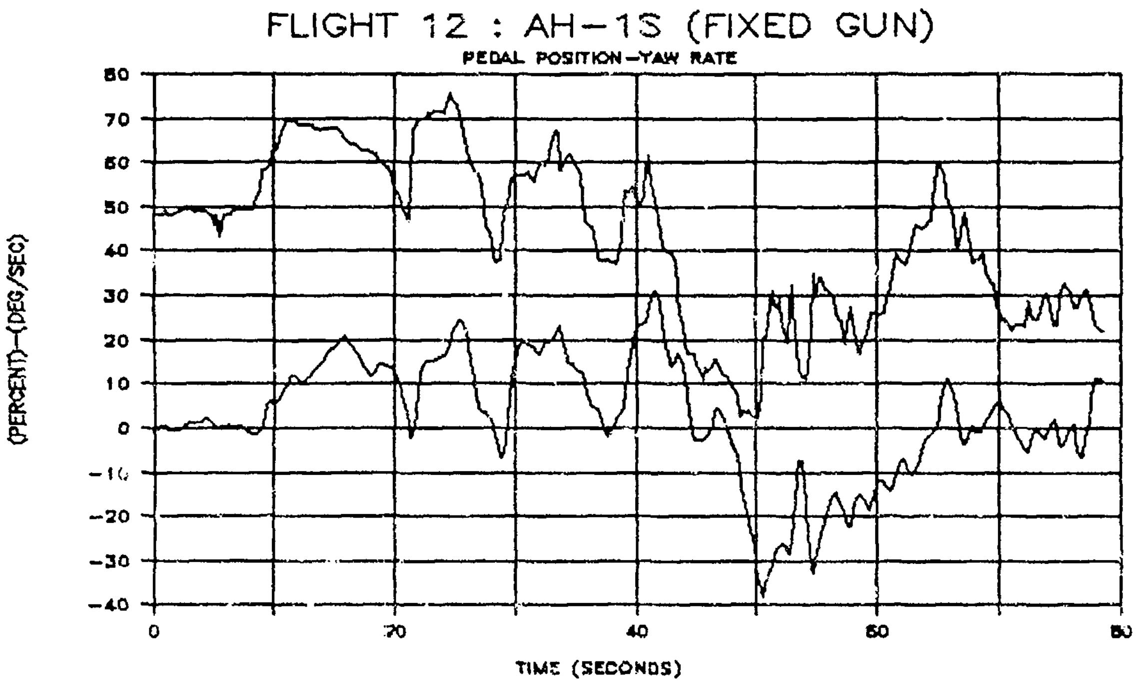
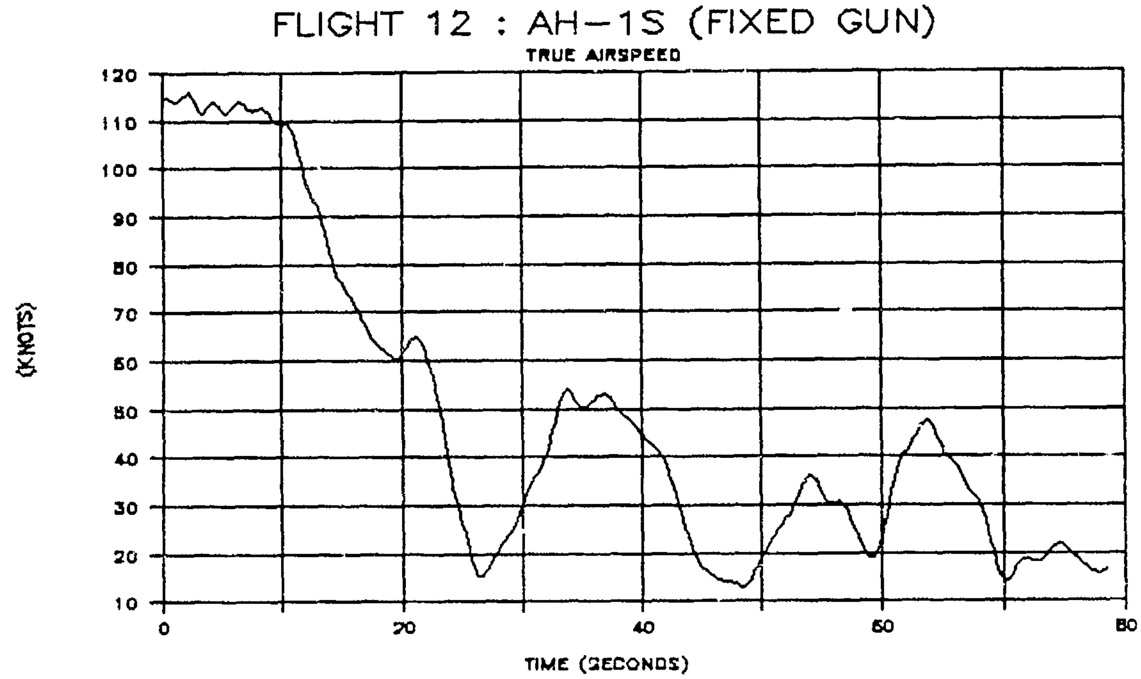


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Continued)



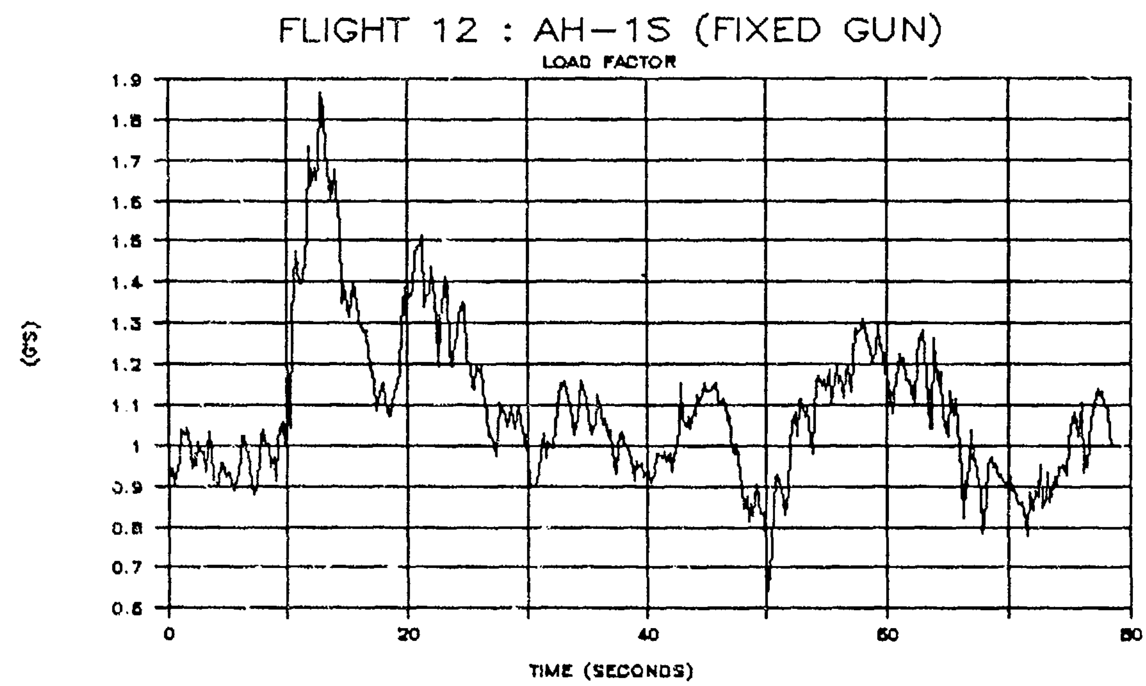
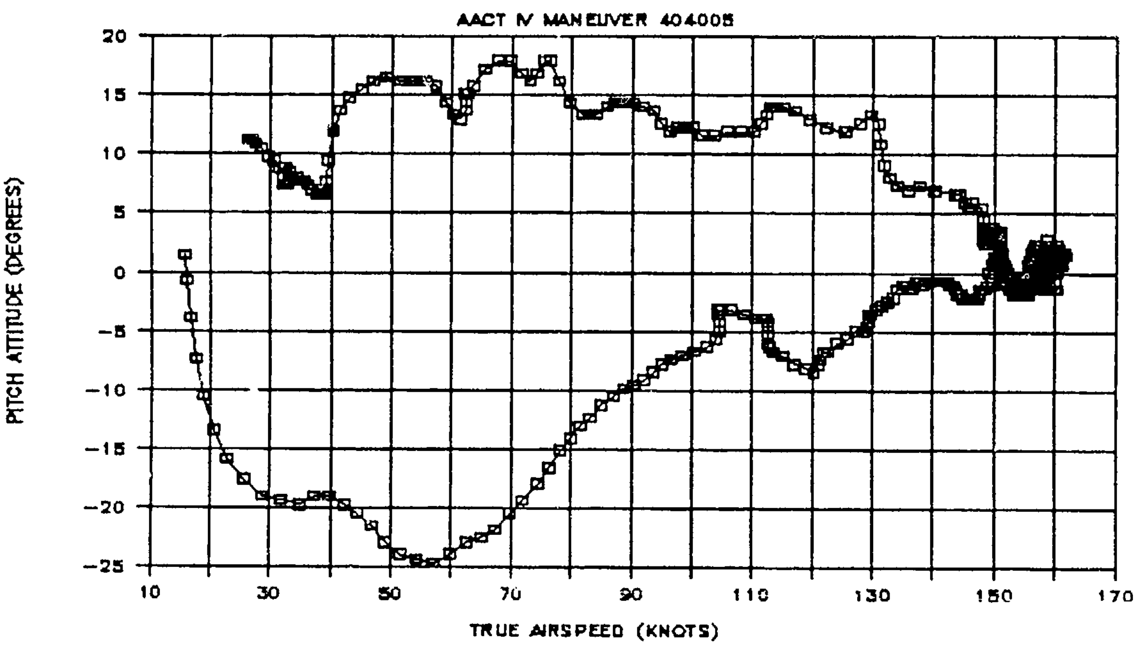


Figure 23. Head-to-head engagement time histories - AH-64A vs AH-1S. (Concluded)



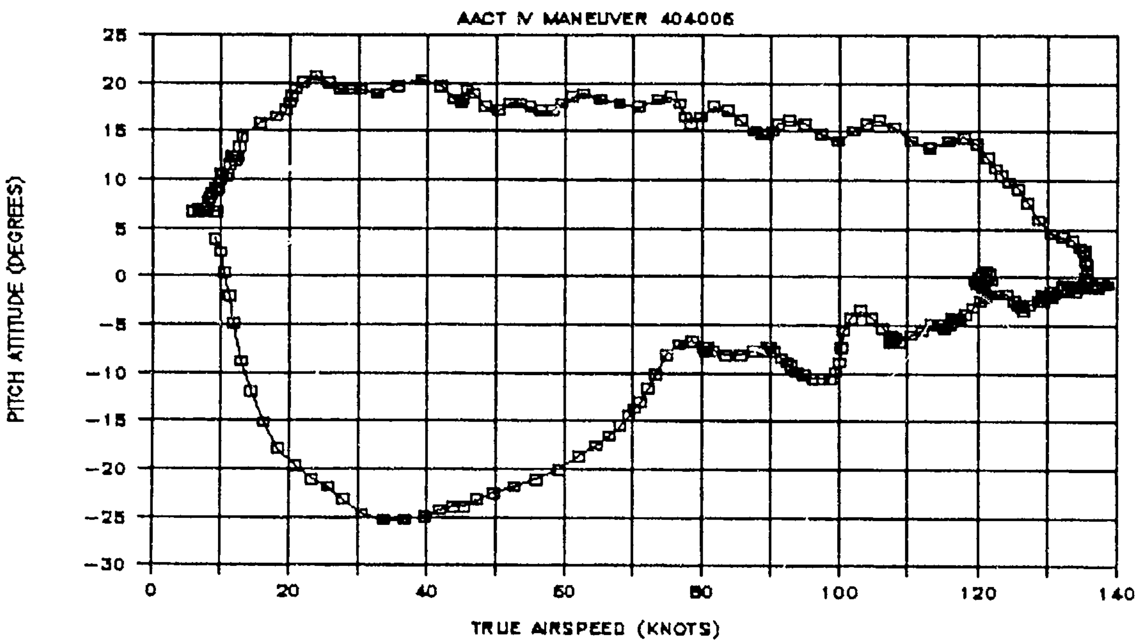


Figure 24. Acceleration/deceleration pitch attitude vs airspeed for SA-365N-1.

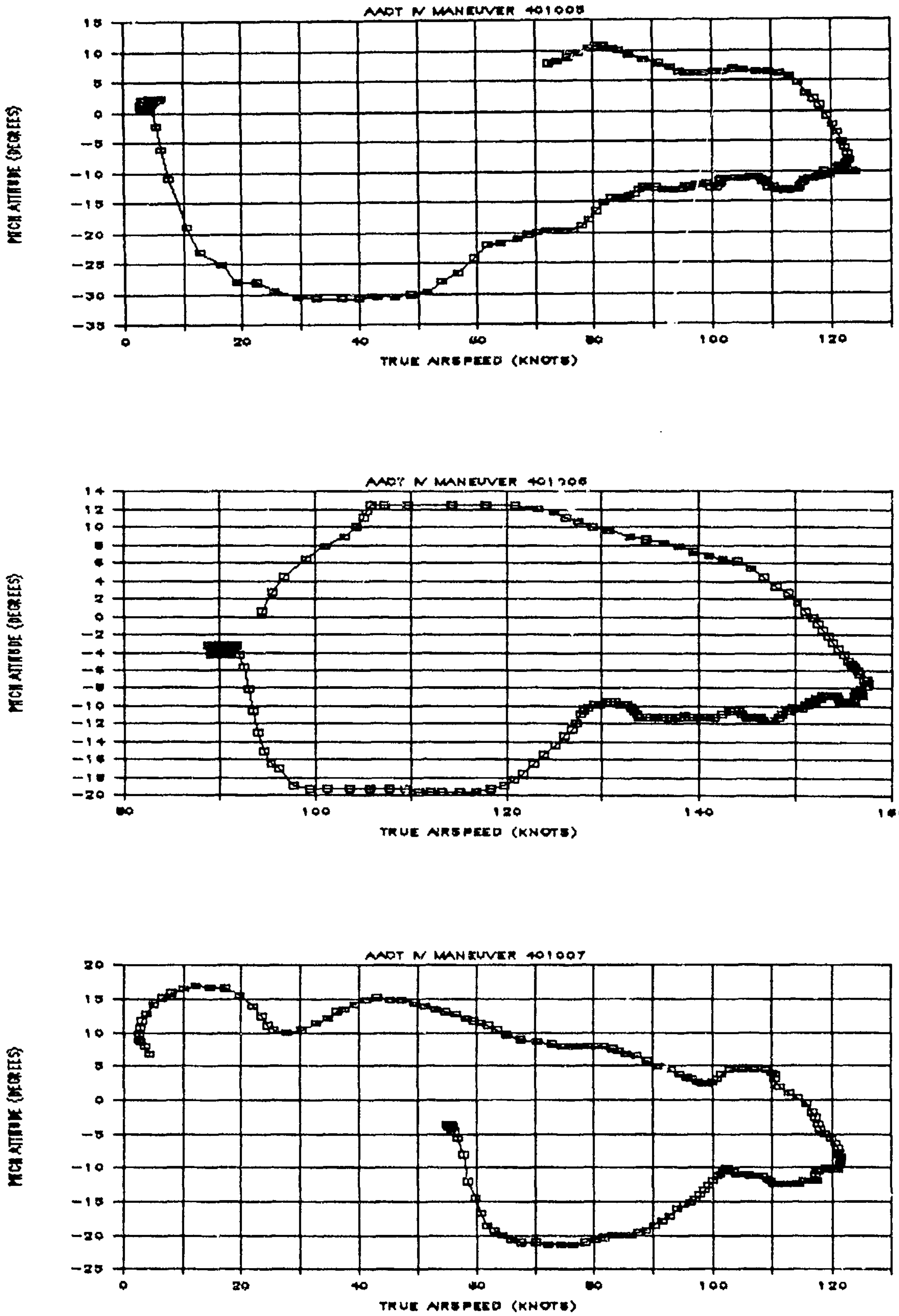


Figure 25. Acceleration/deceleration pitch attitude vs airspeed for AH-64A.

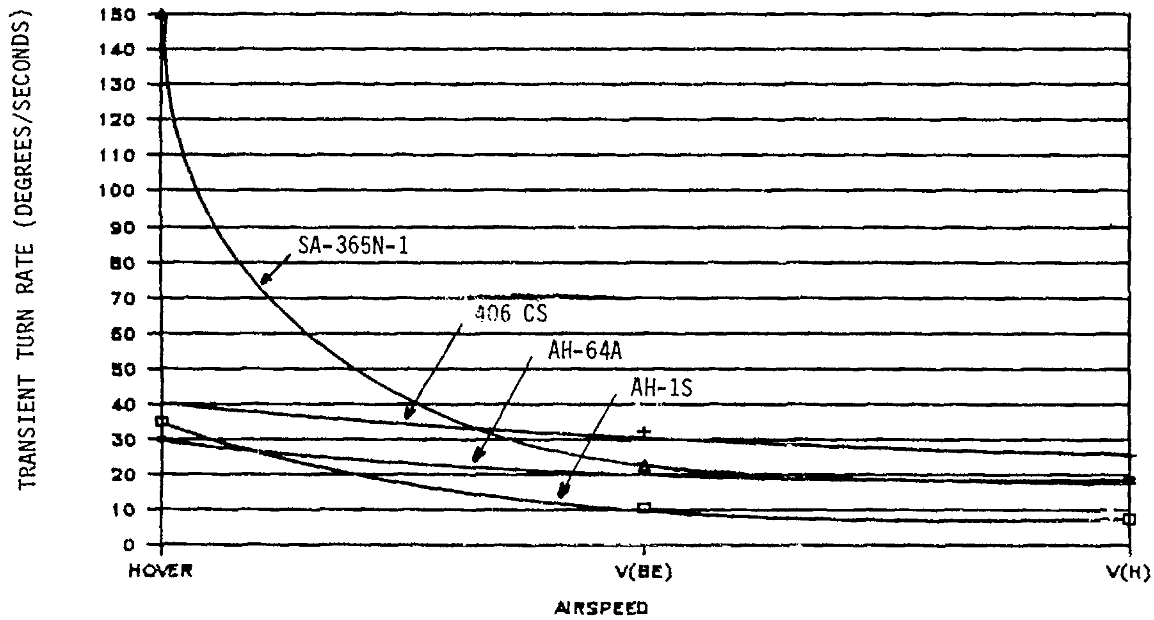


Figure 26. Transient turn rate vs airspeed.

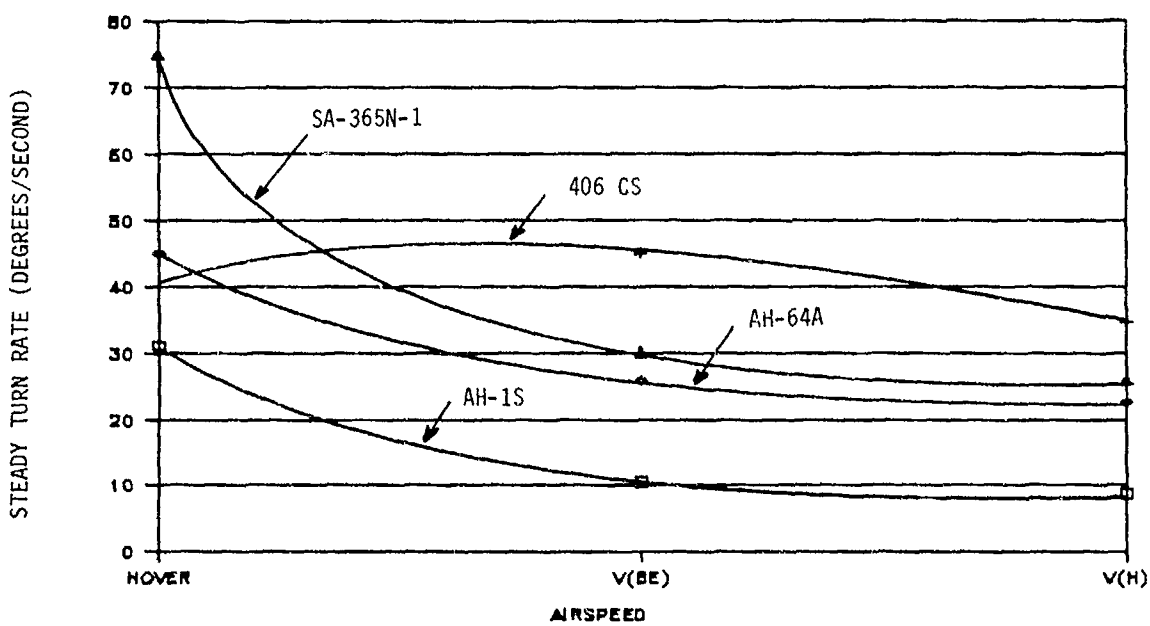


Figure 27. Steady turn rate vs airspeed.

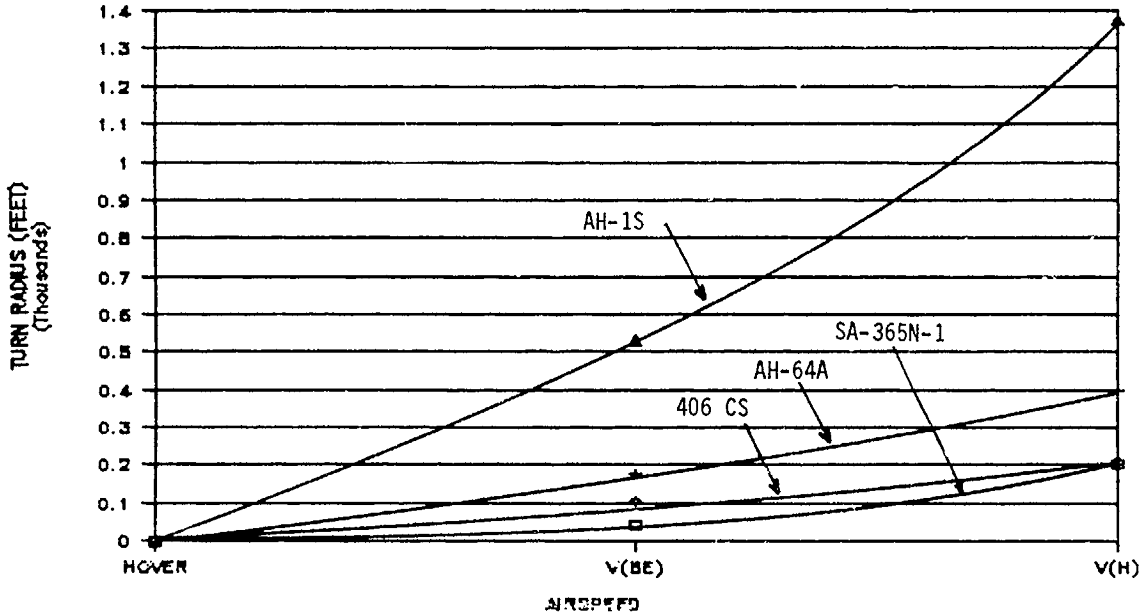


Figure 28. Turn radius vs airspeed.

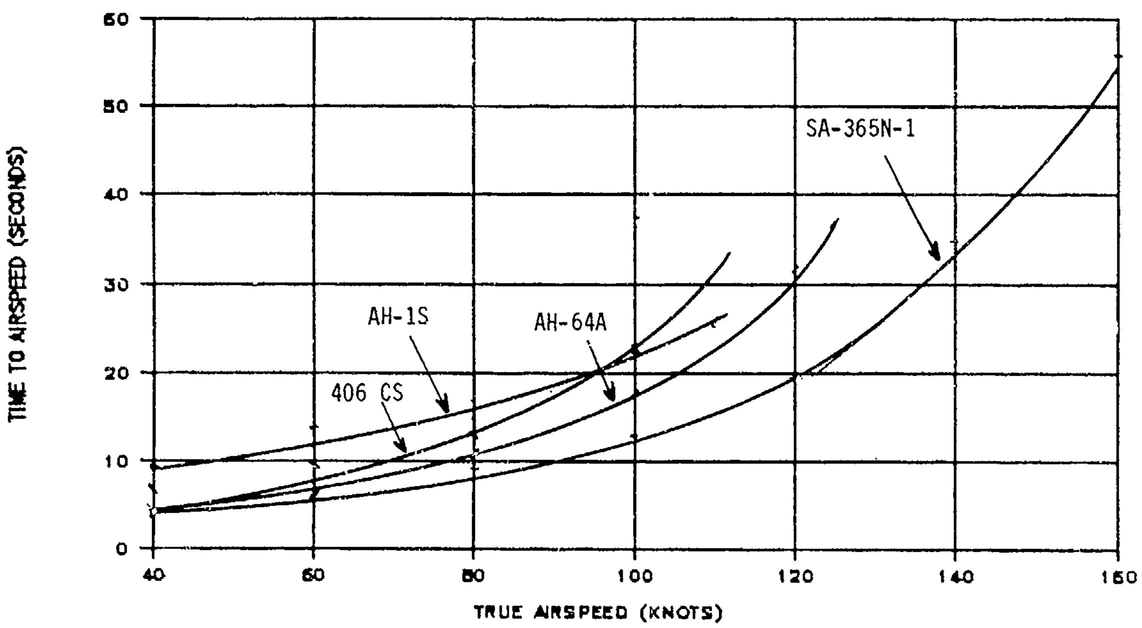


Figure 29. Time to accelerate.

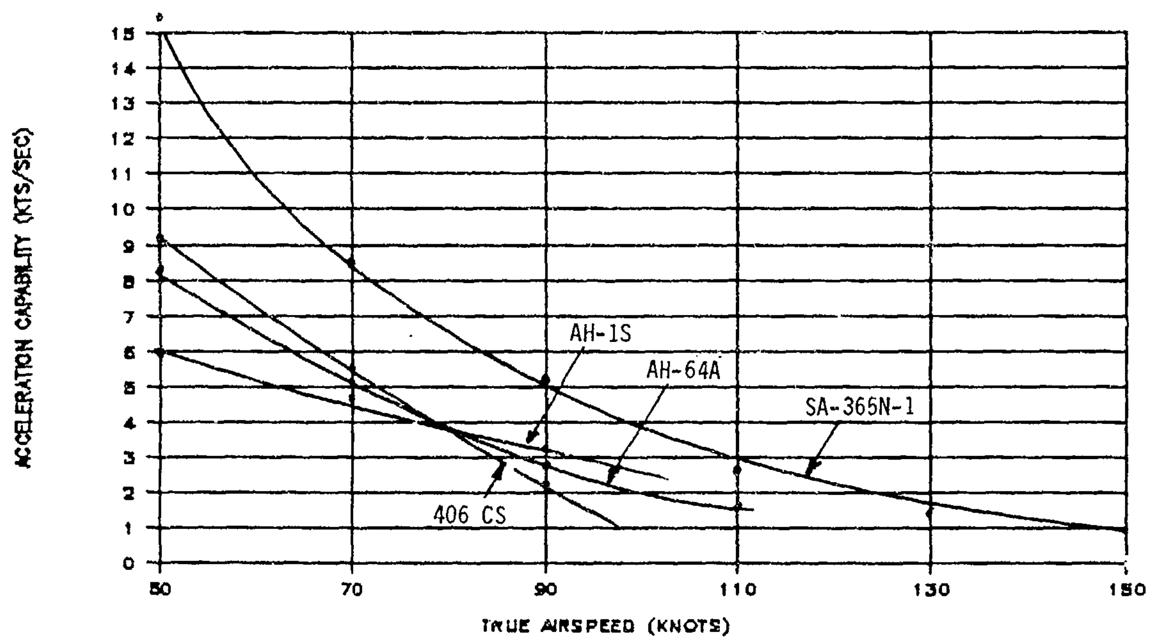


Figure 30. Acceleration capability.

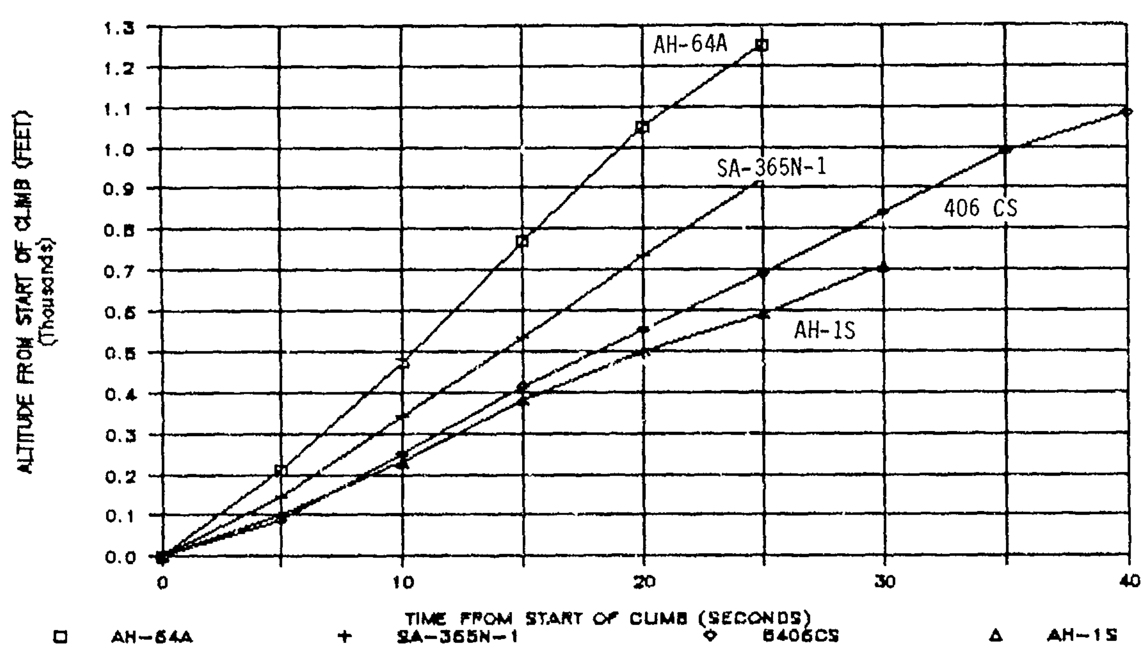


Figure 31. Climb performance.

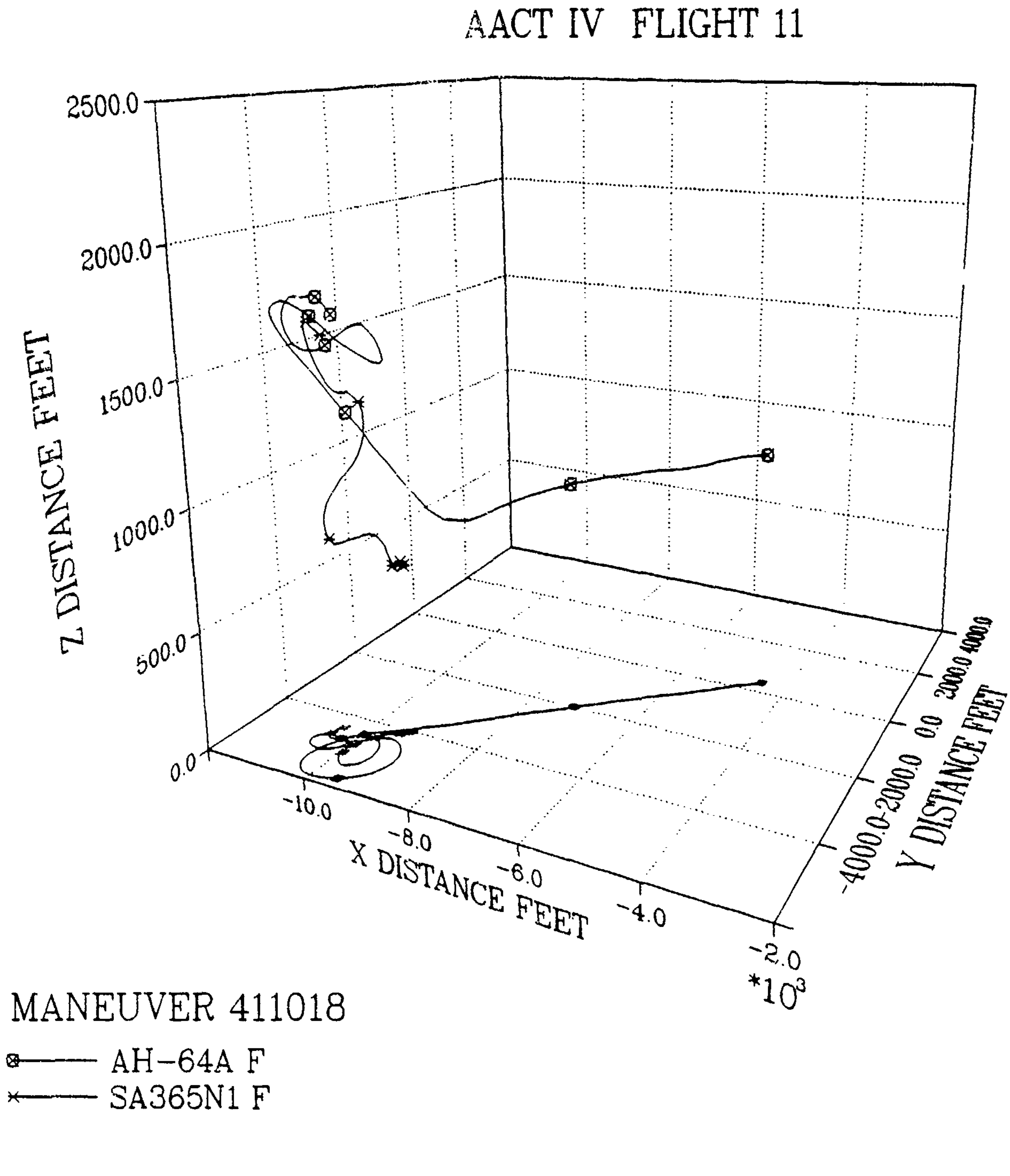


Figure 32. Three-dimensional flight path - AH-64A vs SA-365N-1.

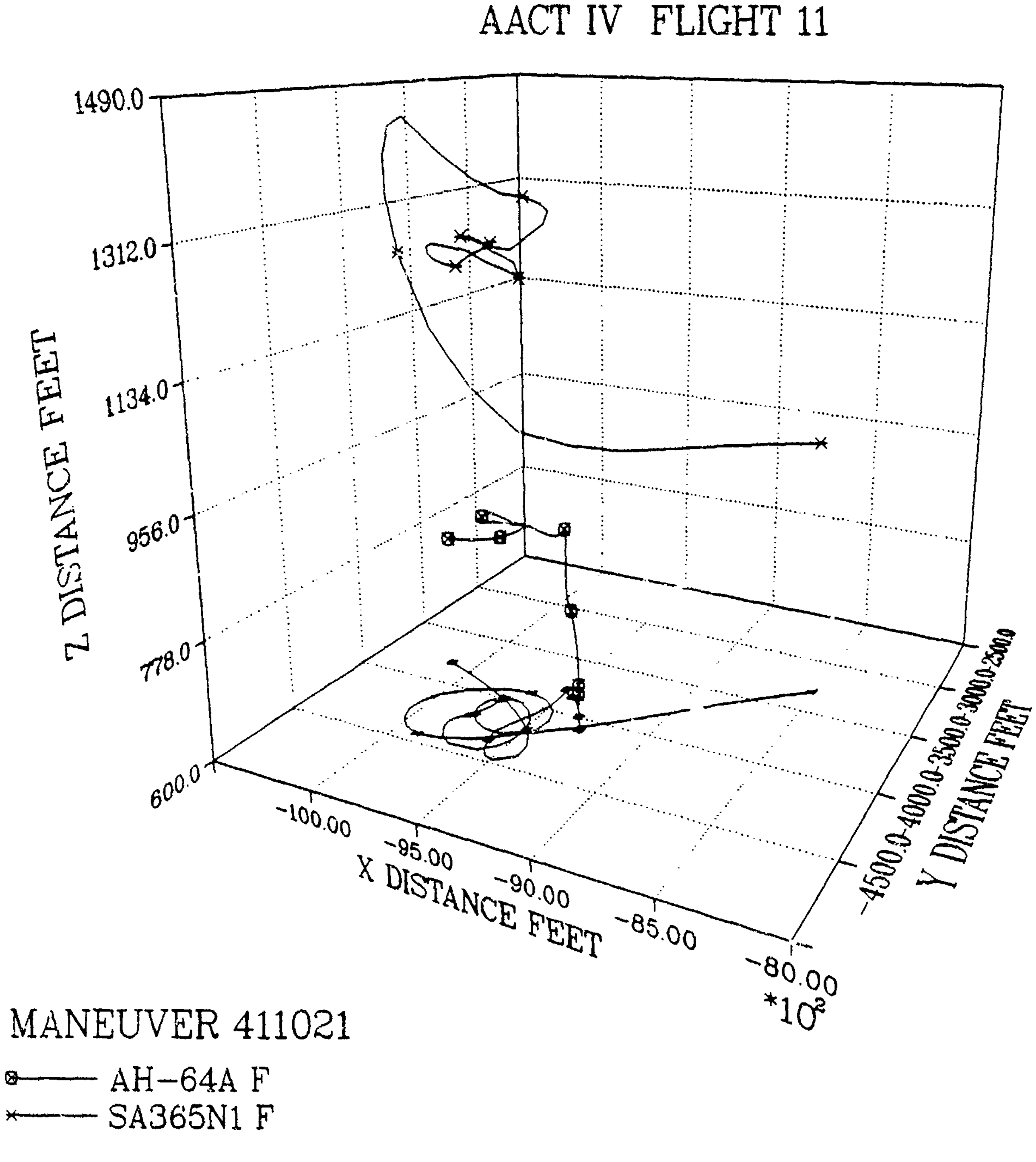
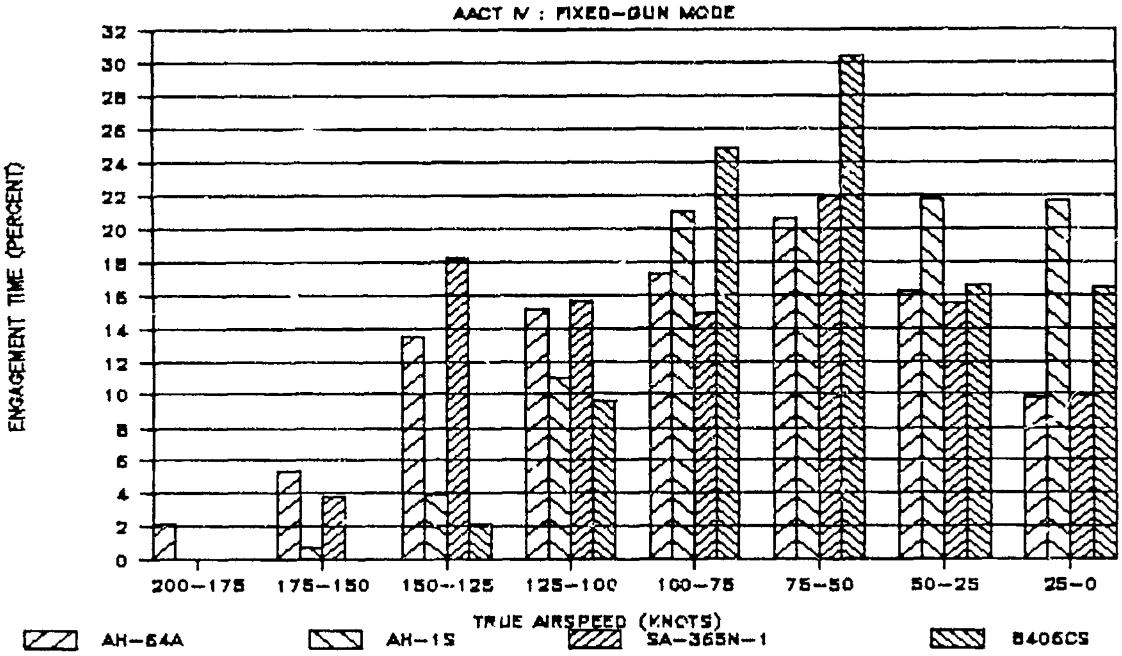


Figure 33. Three-dimensional flight path - SA-365N-1 vs AH-64A.



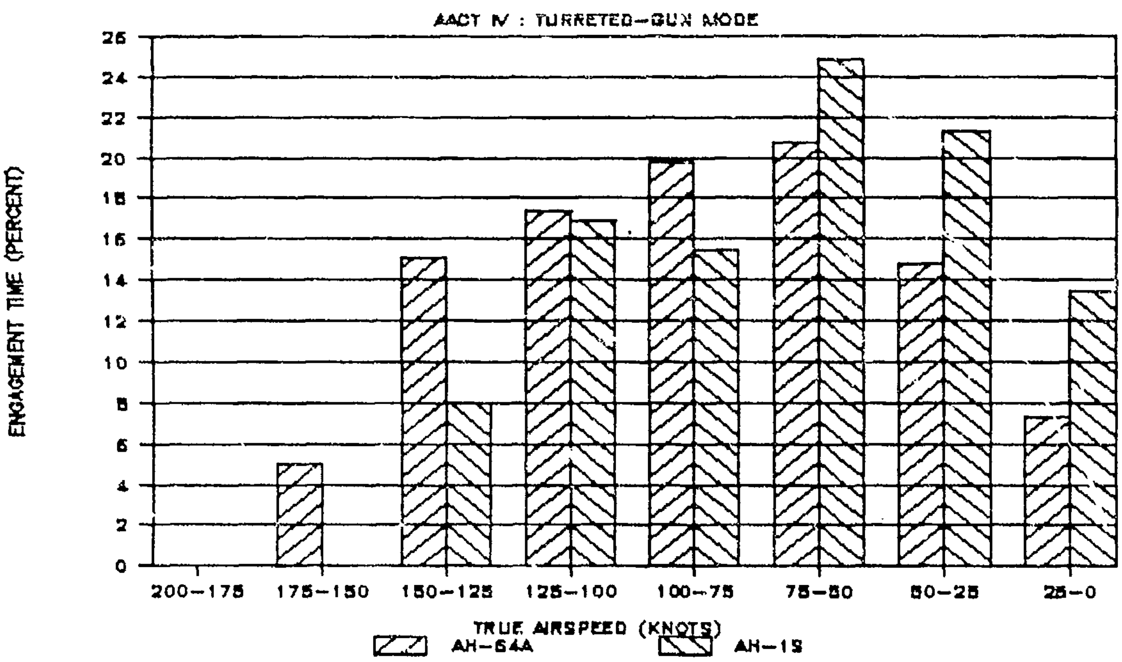


Figure 34. True airspeed histograms - fixed and turreted gun modes.

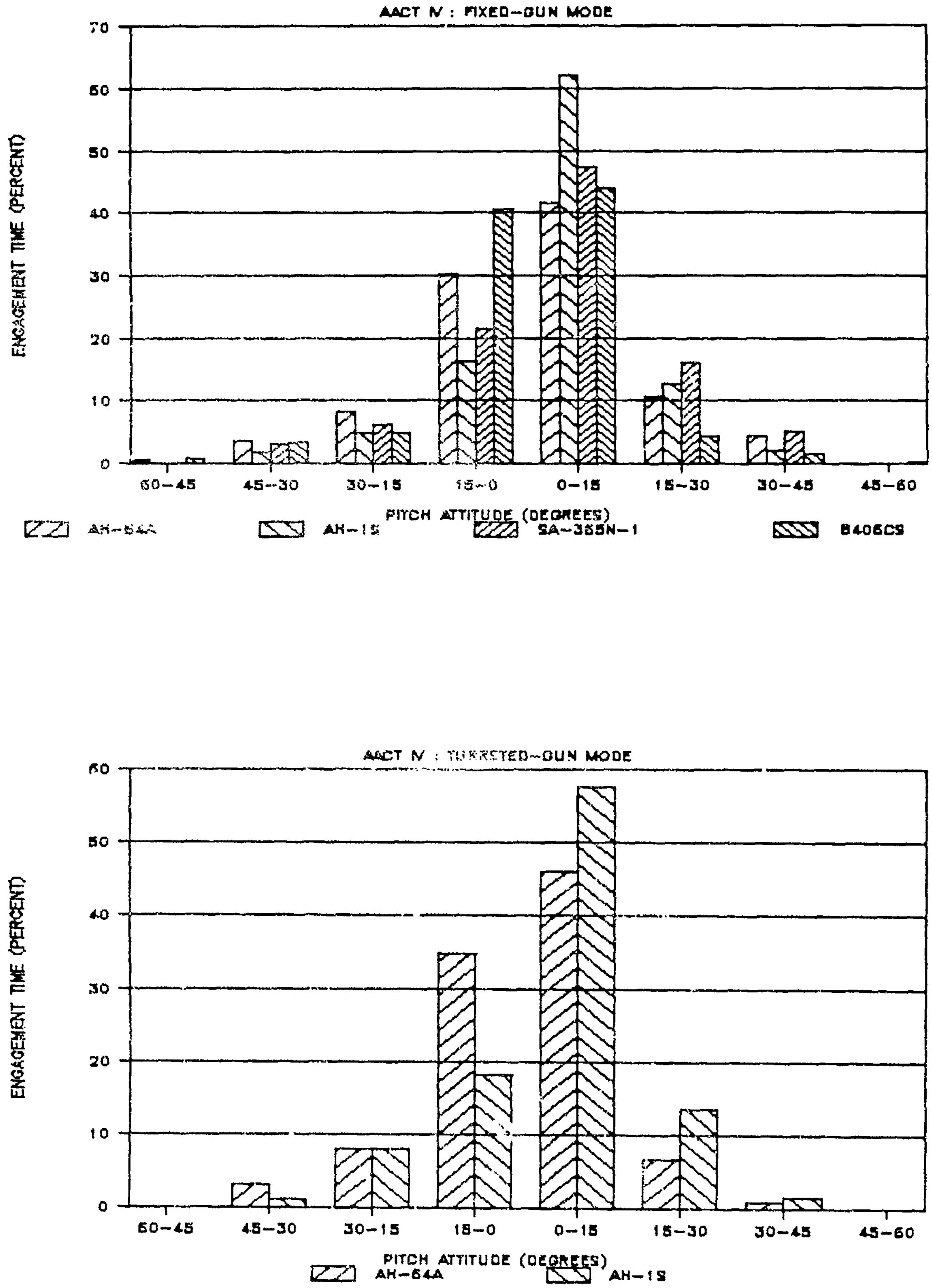
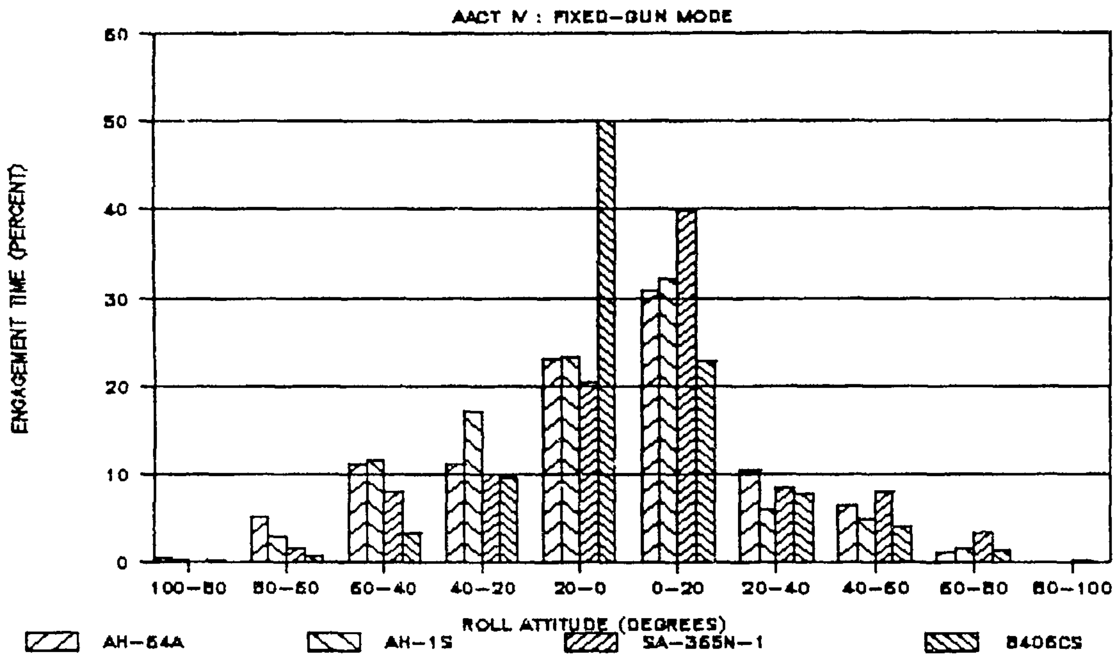


Figure 35. Pitch attitude histograms - fixed and turreted gun modes.



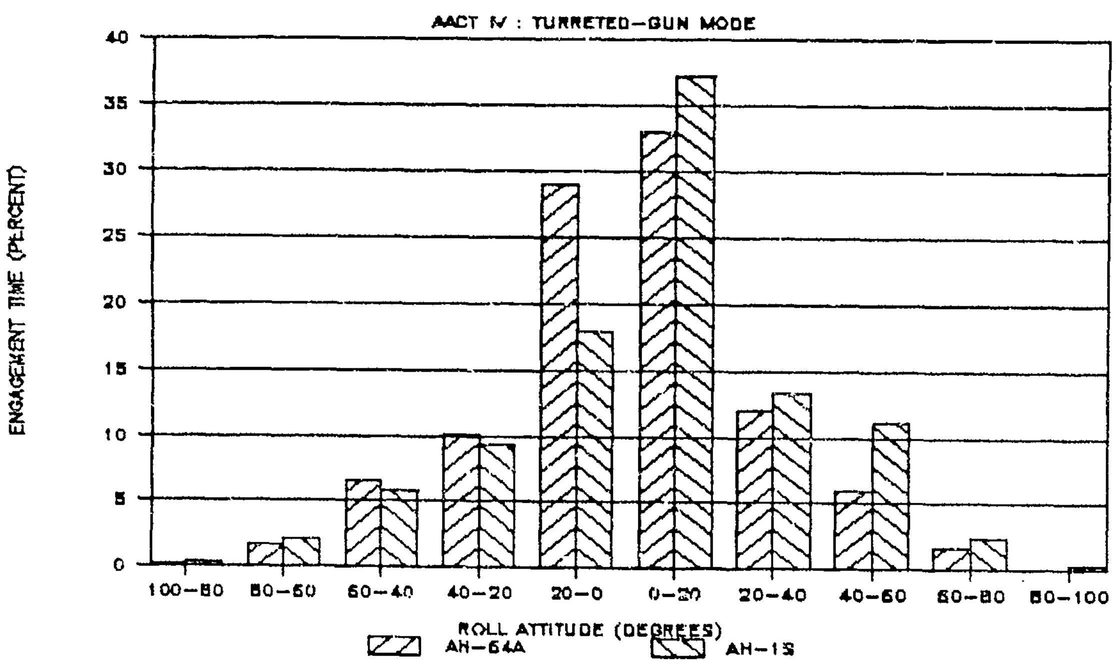
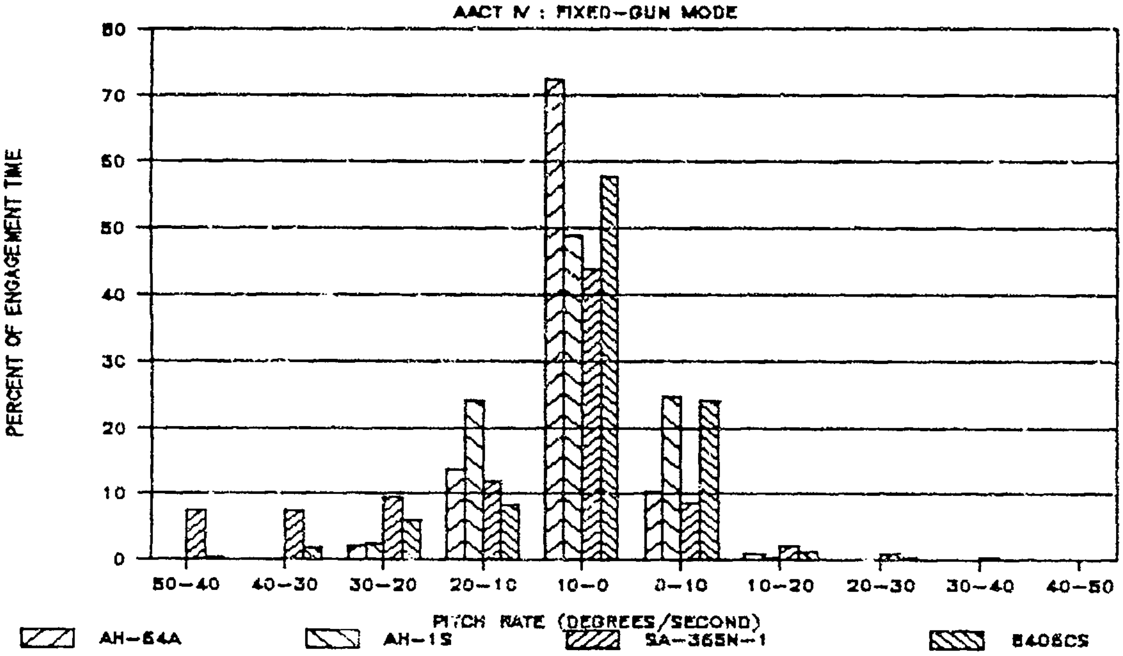


Figure 36. Roll attitude histograms - fixed and turreted gun modes.



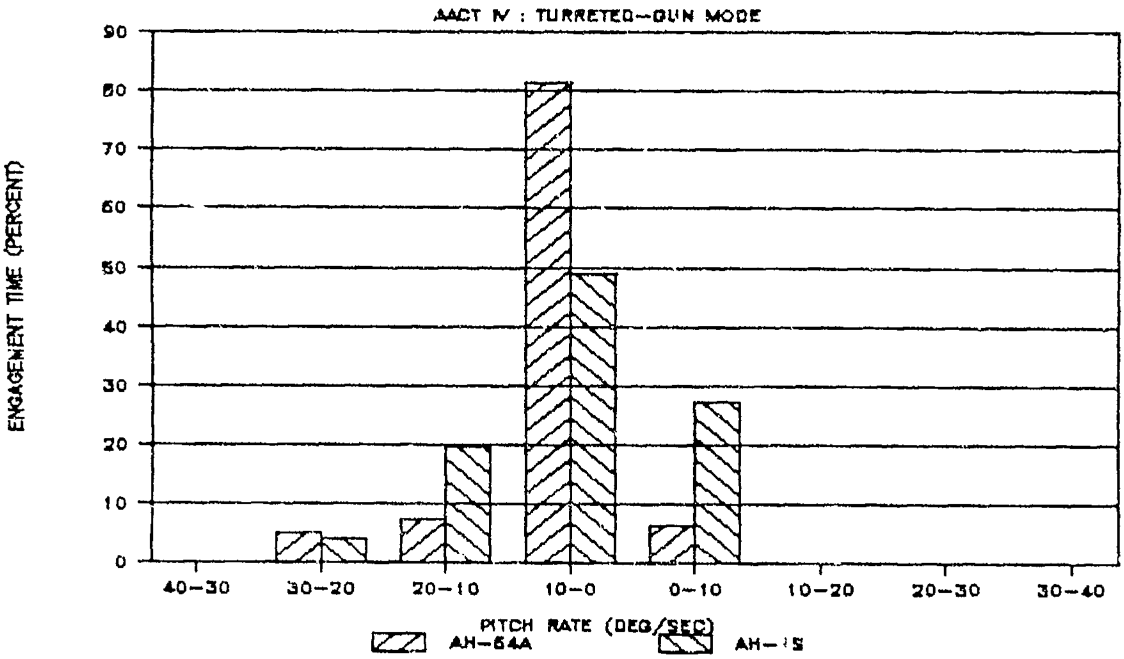
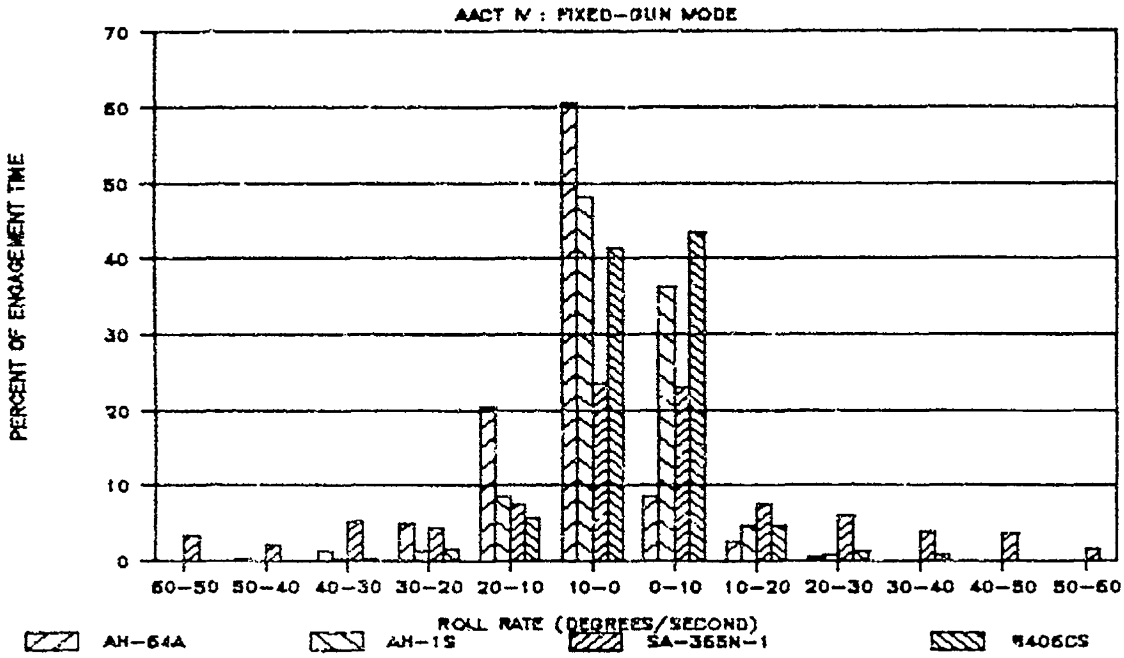


Figure 37. Pitch rate histograms - fixed and turreted gun modes.



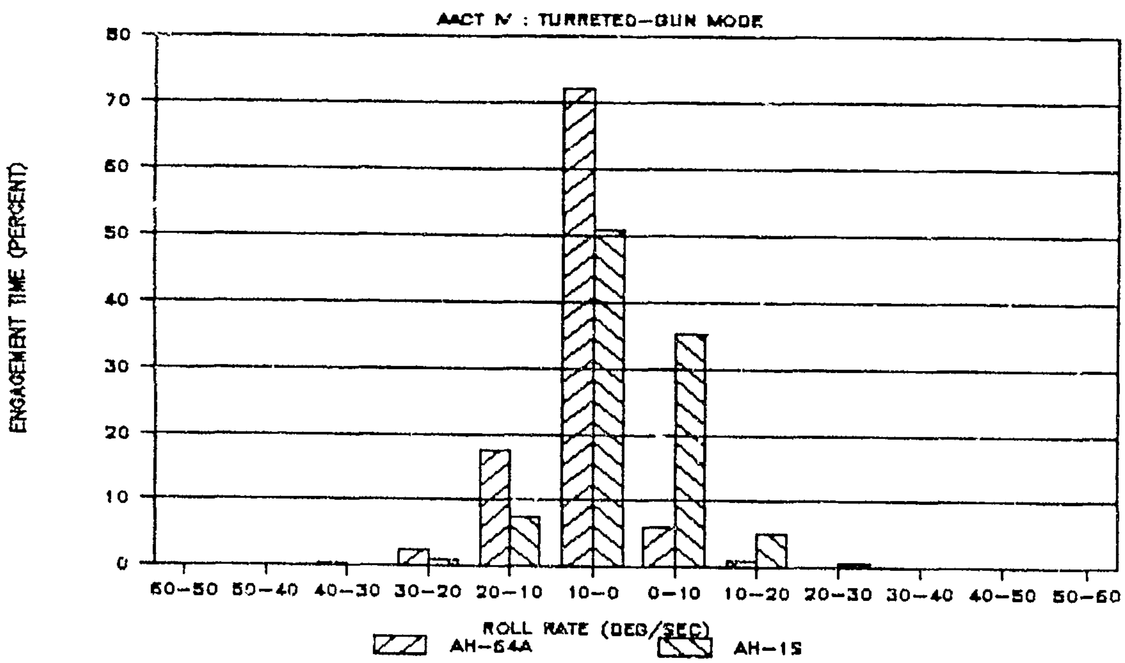
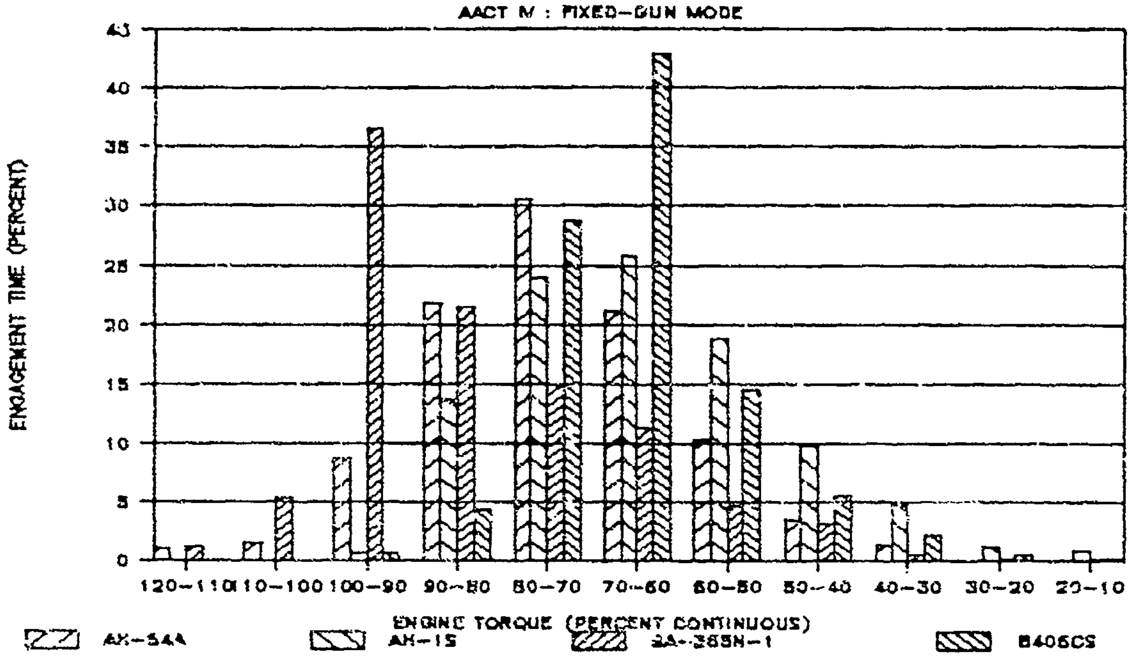


Figure 38. Roll rate histograms - fixed and turreted gun modes.



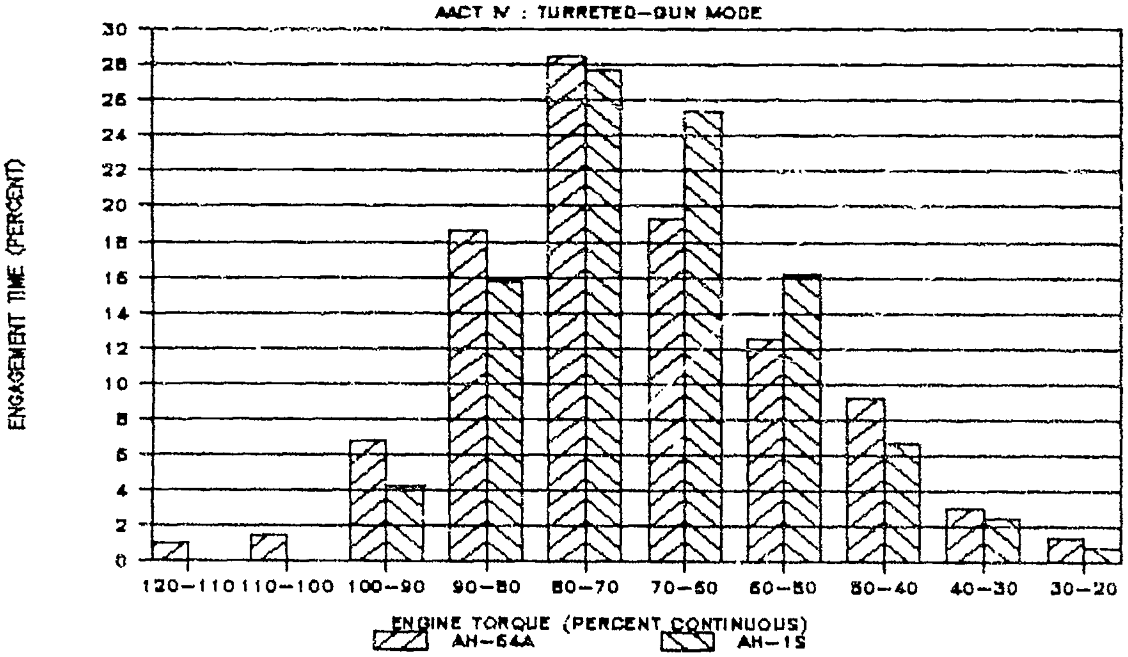
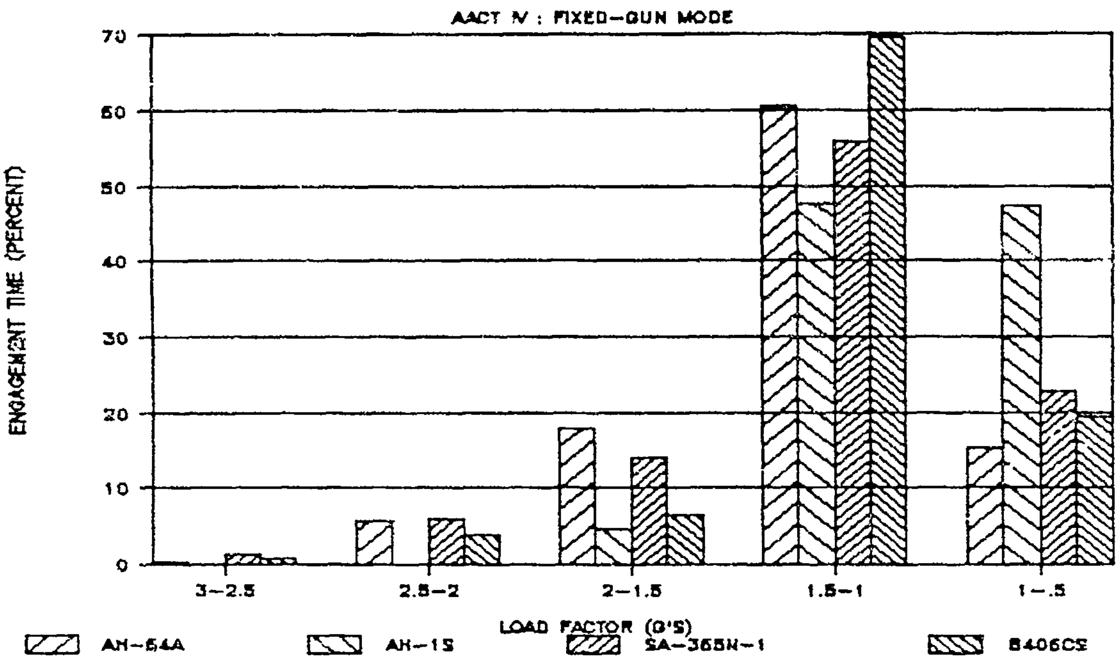


Figure 39. Engine torque histograms - fixed and turreted gun modes.



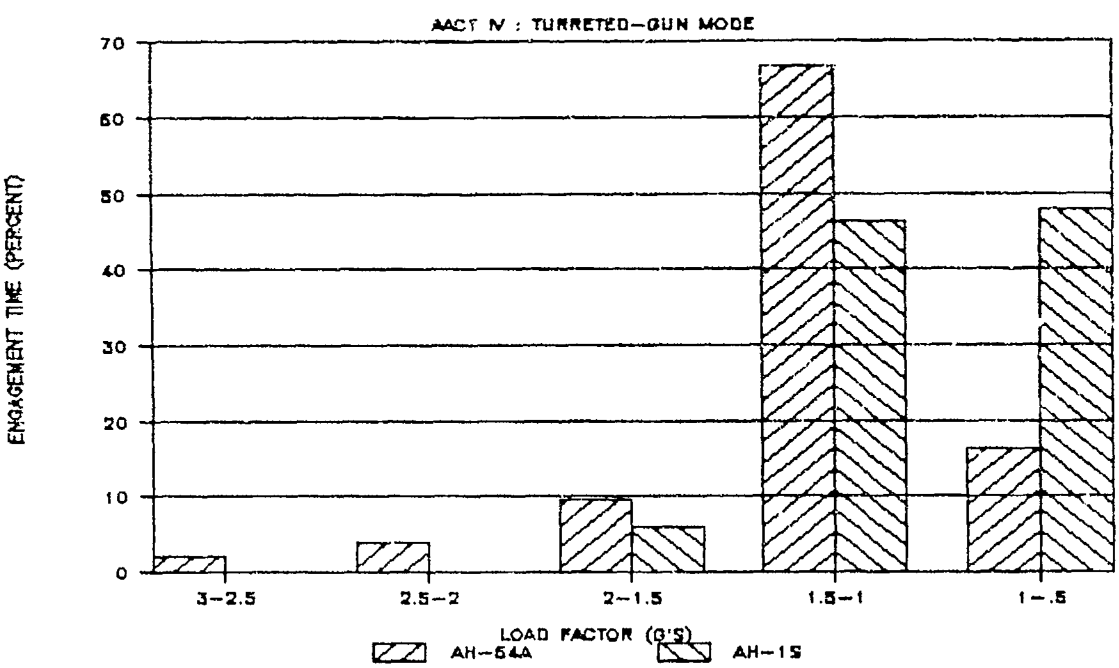


Figure 40. Load factor histograms - fixed and turreted gun modes.

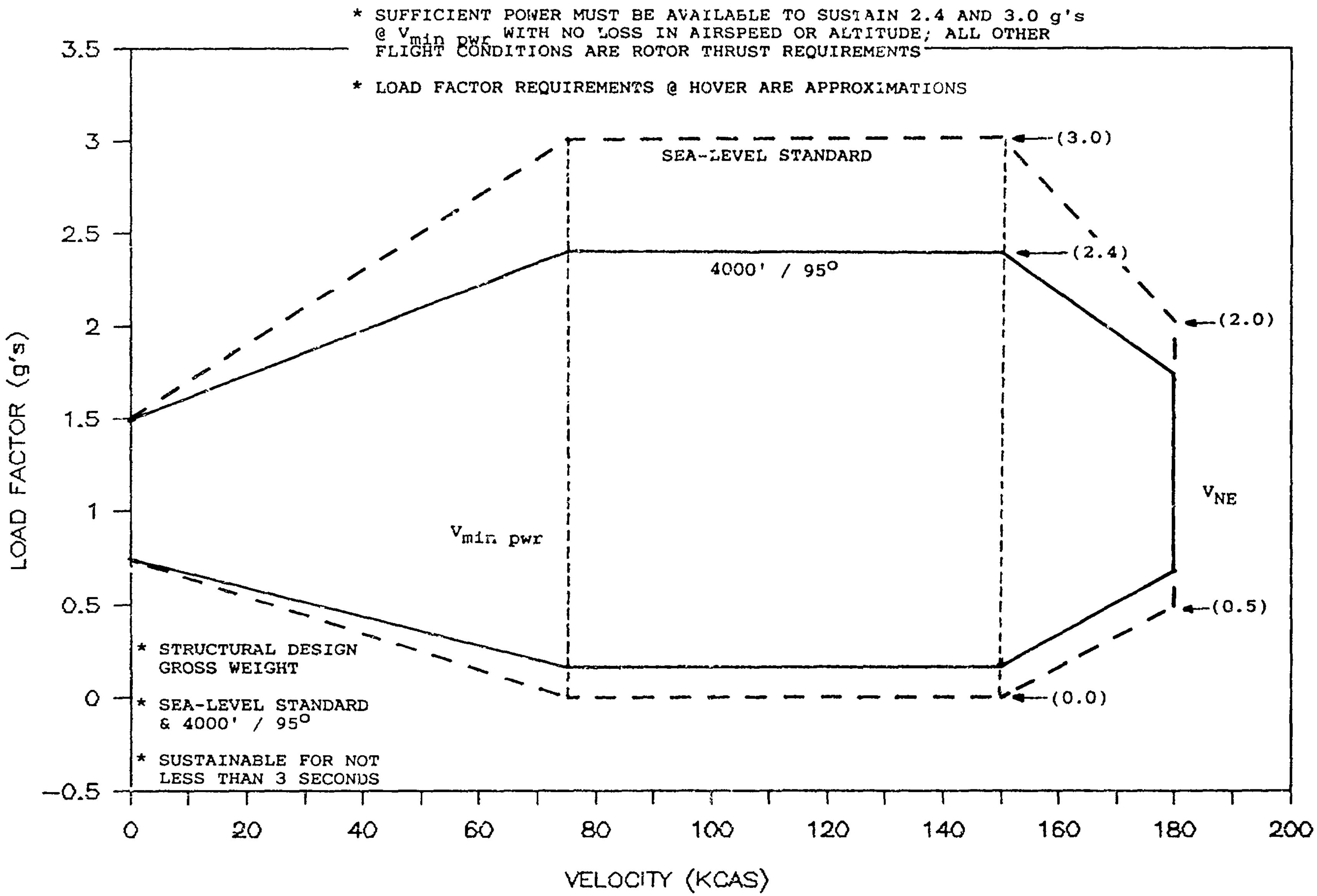


Figure 41. Recommended load factor diagram.

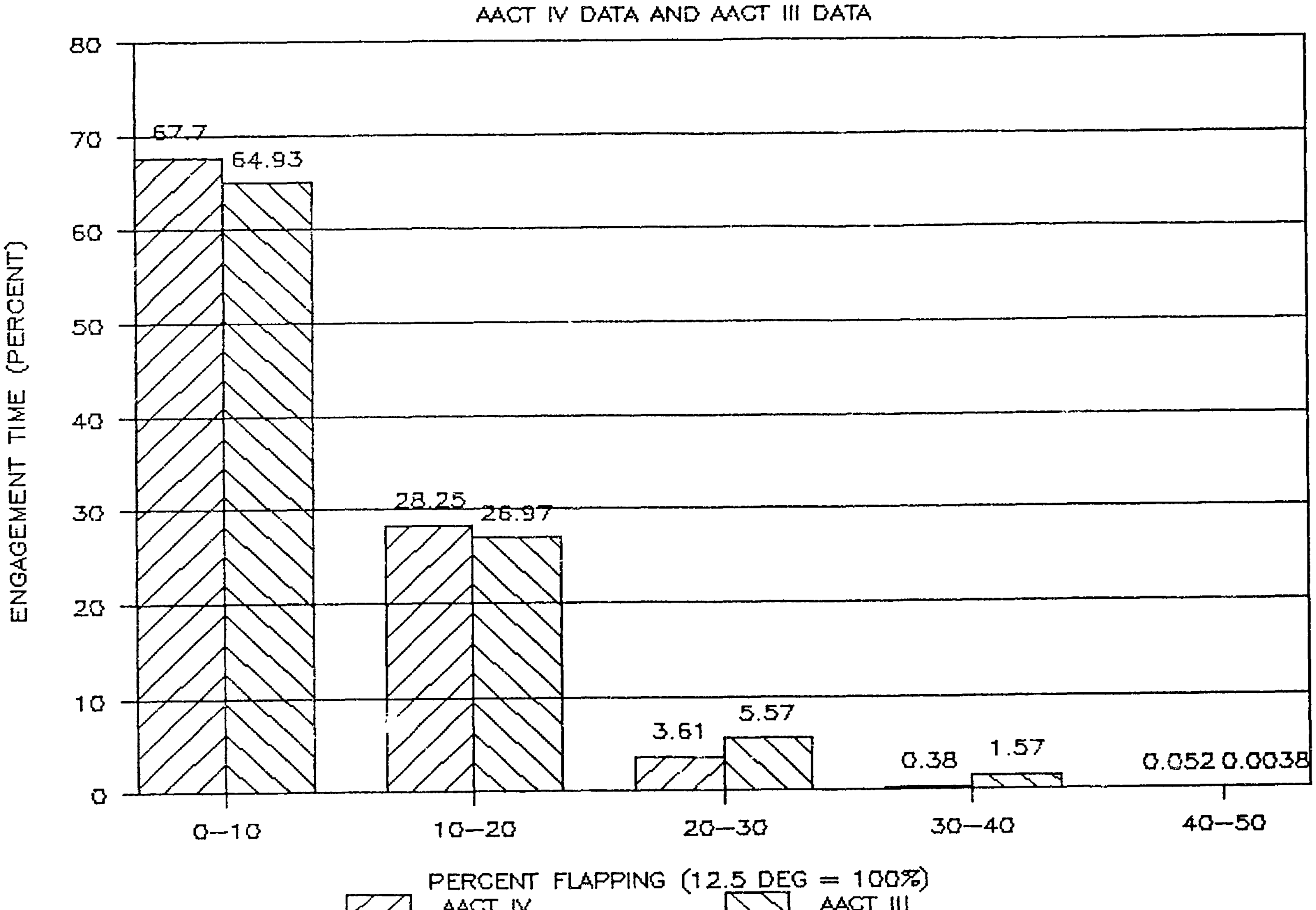
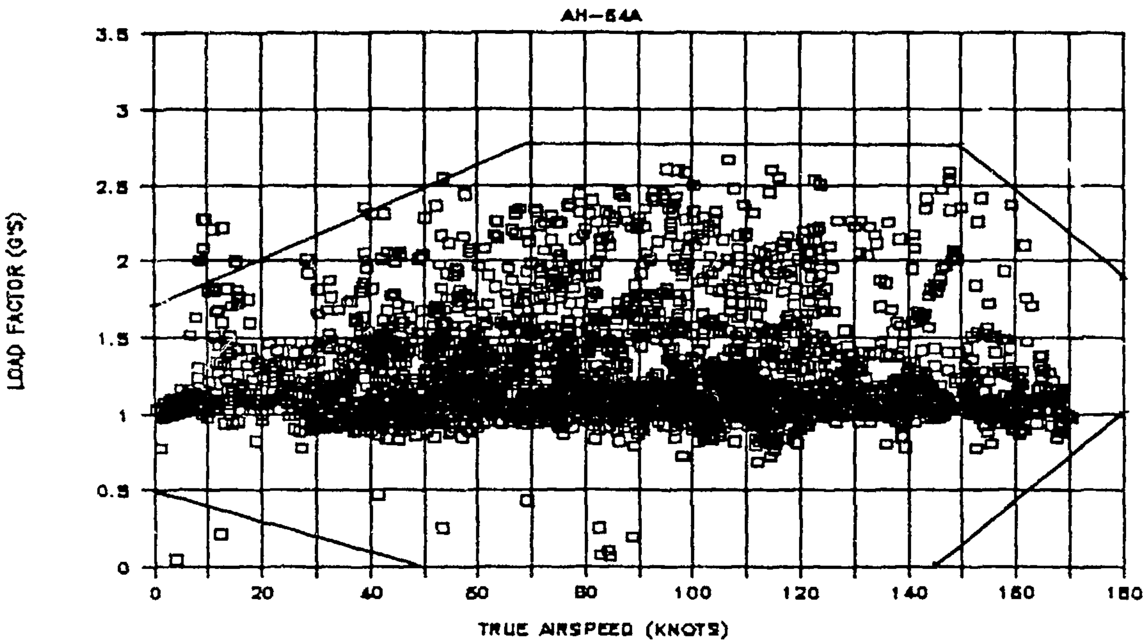


Figure 42. AH-1S Cobra flapping histogram.



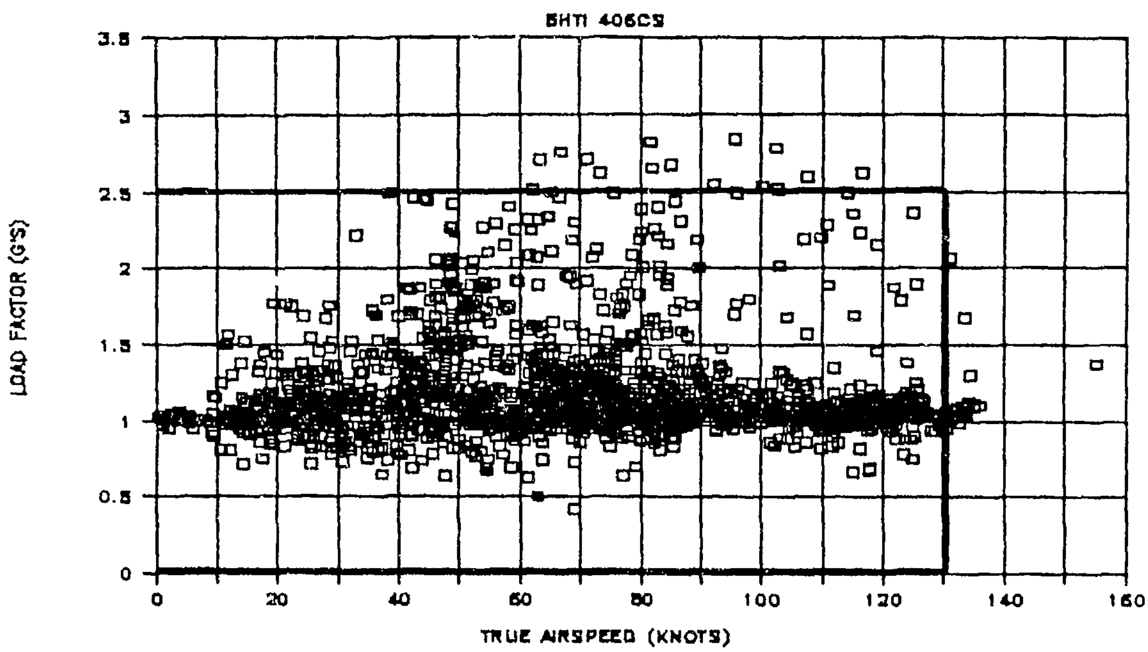
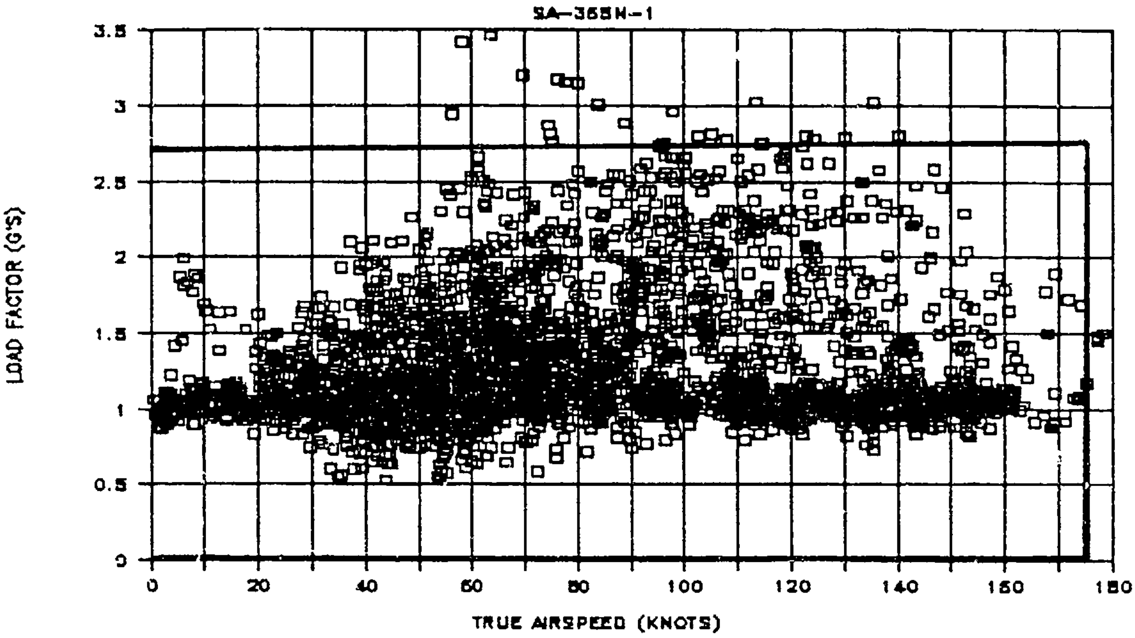


Figure 43. ACM load factor vs airspeed data excursion envelopes.



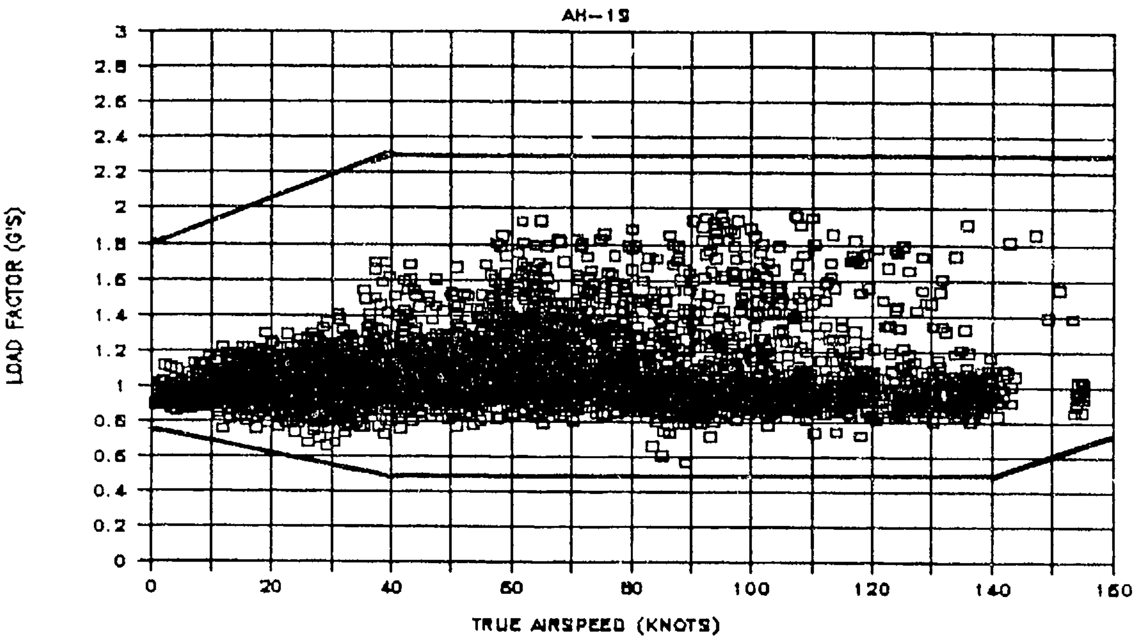


Figure 43. ACM load factor vs airspeed data excursion envelopes. (Concluded)

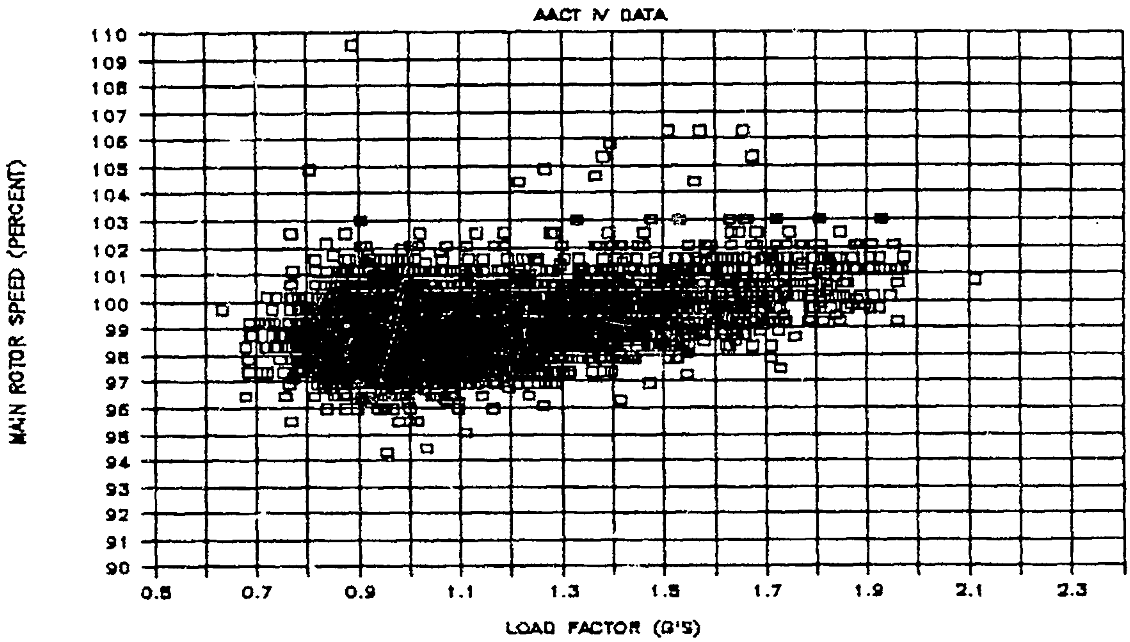


Figure 44. AH-1S rotor speed vs load factor data excursions.

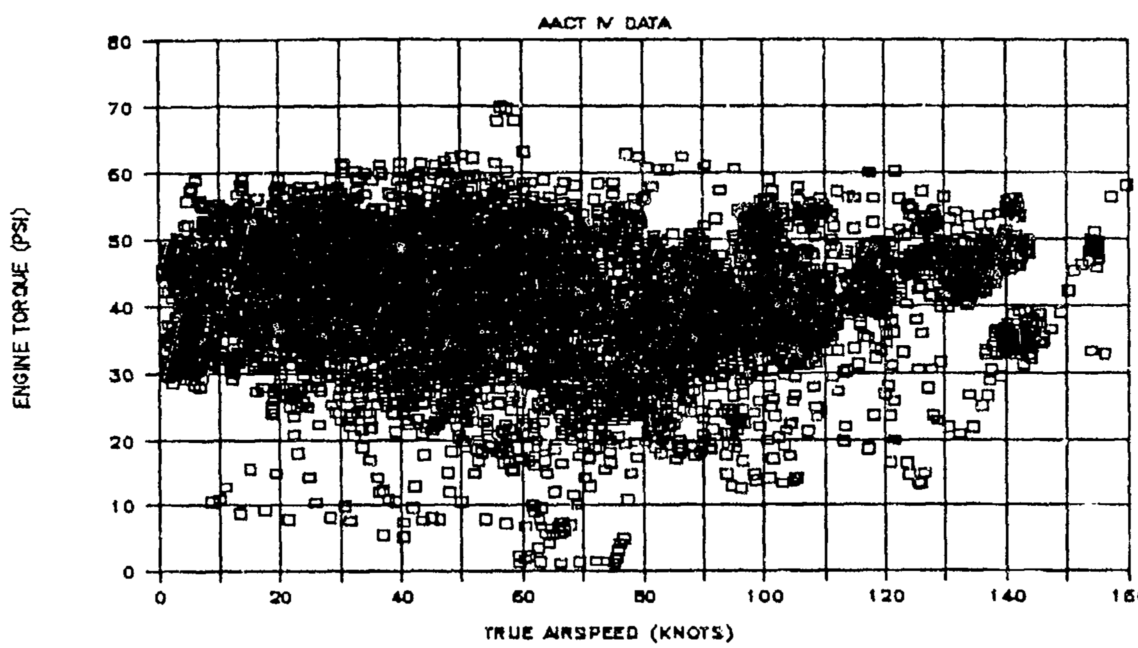
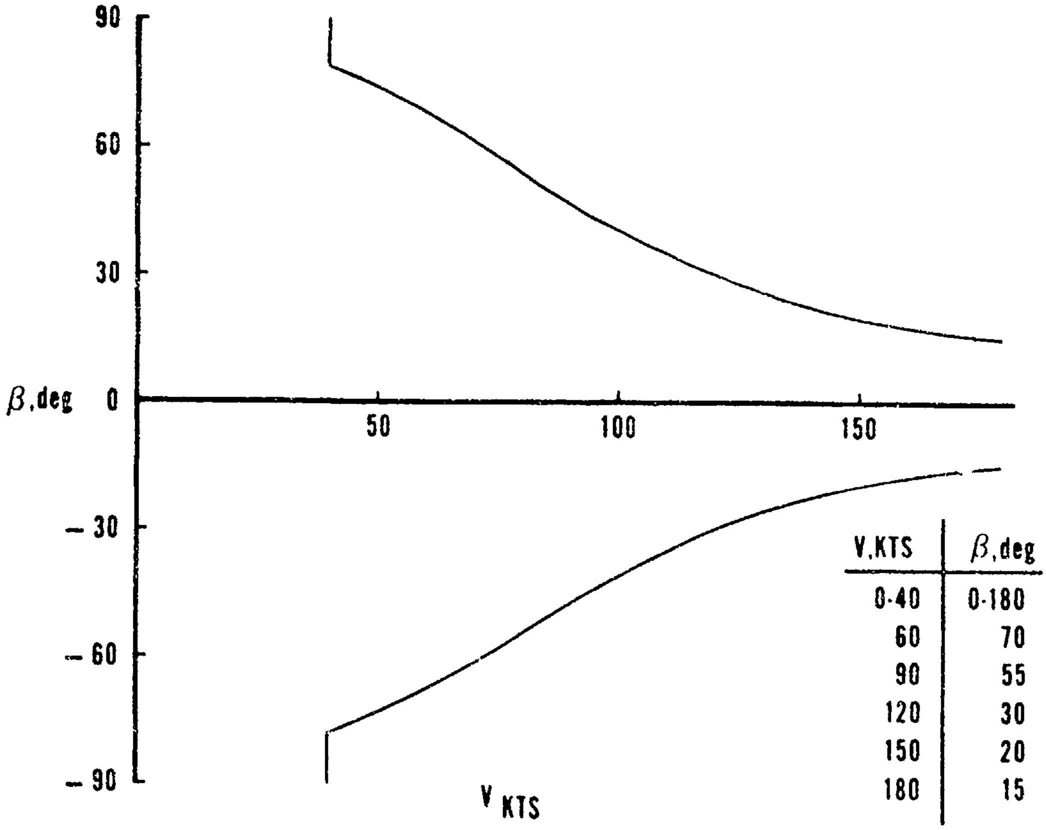
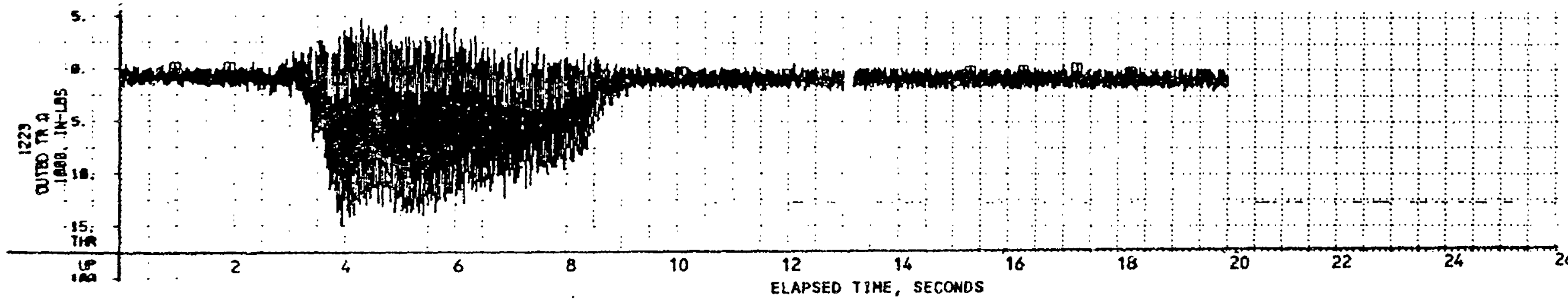


Figure 45. AH-1S engine torque vs airspeed data excursions.



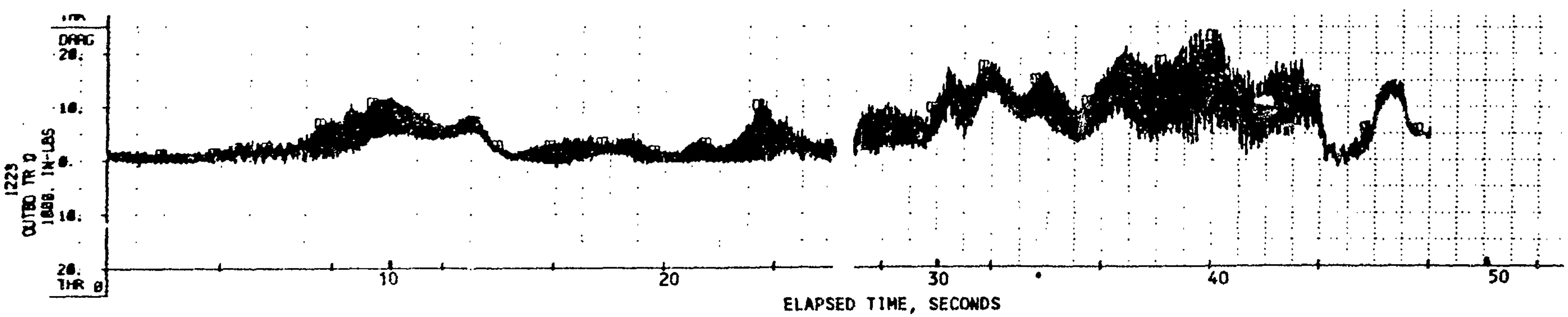
V,KTS	β,deg
0-40	0-180
60	70
90	55
120	30
150	20
180	15

Figure 46. Minimum recommended sideslip requirements.



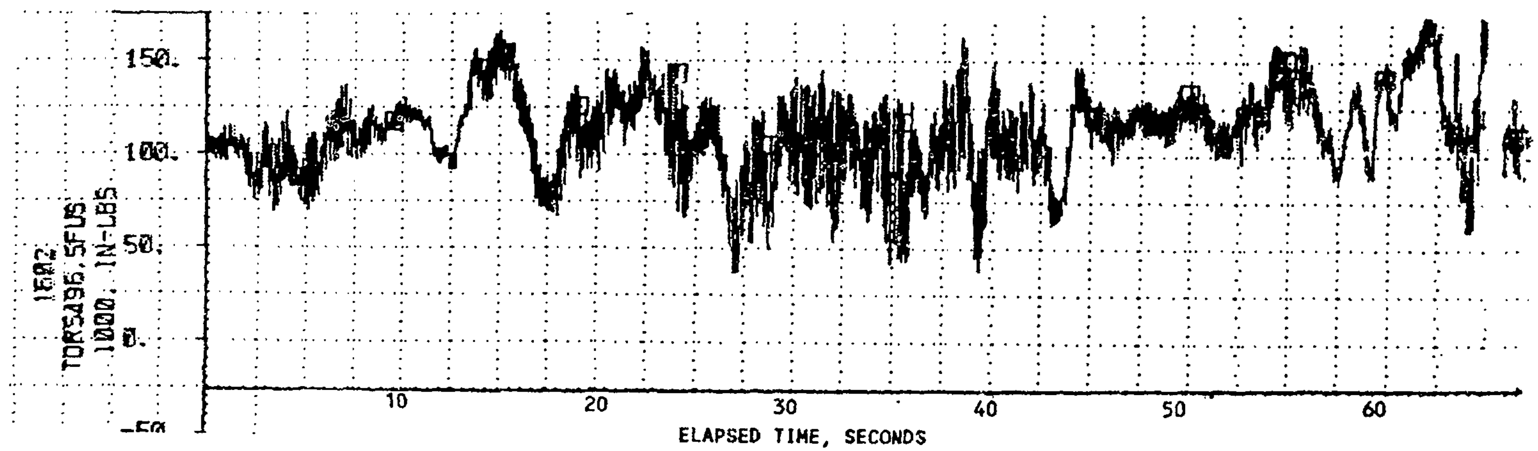
360 DEGREE ROLL LEFT, 130 KNOTS (49623)

Figure 47. AH-64A tail rotor fork torque.



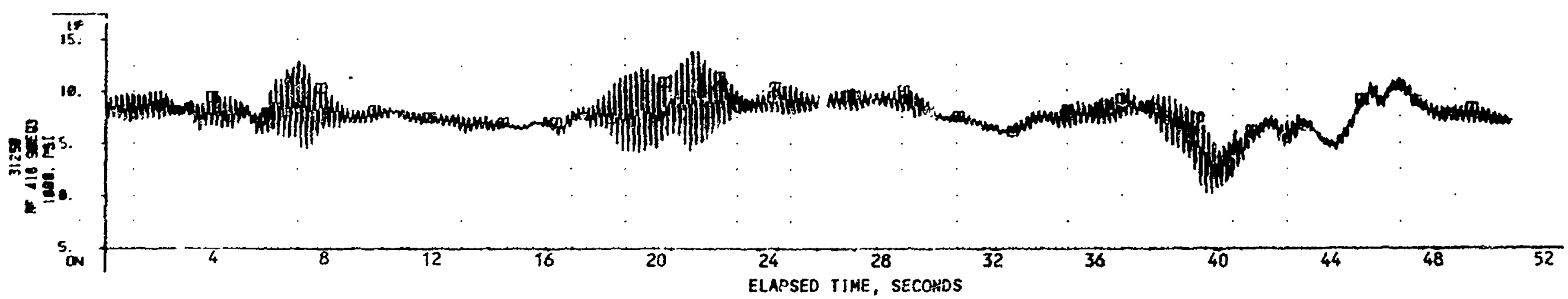
PT. 10A TAIL CHASE (52105)

Figure 48. AH-64A tail rotor gearbox quill shaft torque.



PT. 6B HEAD ON RT–RT (52226)

Figure 49. AH-64A fuselage tail boom skin torsion.



FUSELAGE VERTICAL BENDING GAGE 1772
PT. 9A ABEAM FLYOVER

Figure 50. AH-64A fuselage tail boom stringer vertical bending.

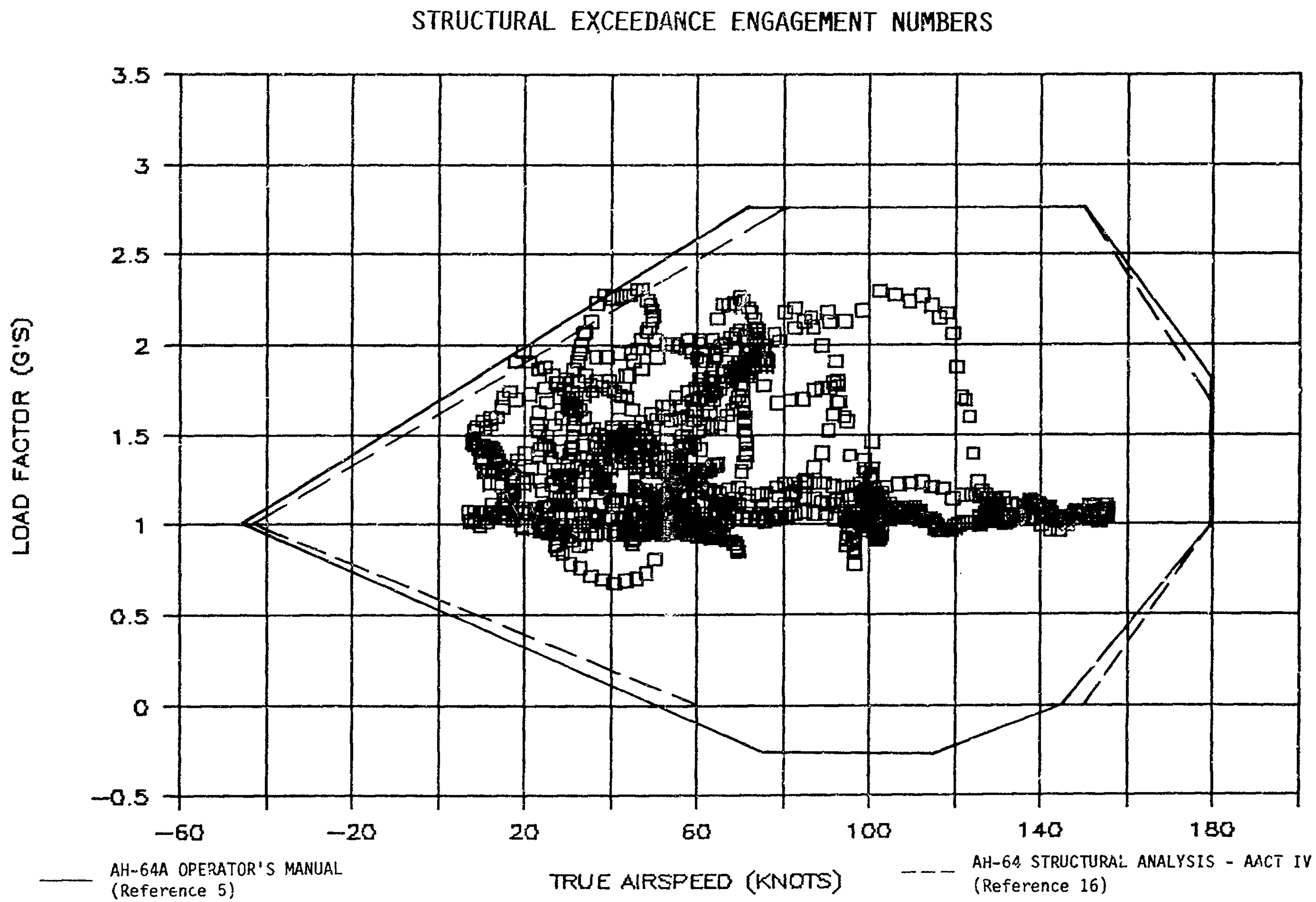


Figure 51. AH-64A load factor vs airspeed data excursions during structural exceedance engagements.

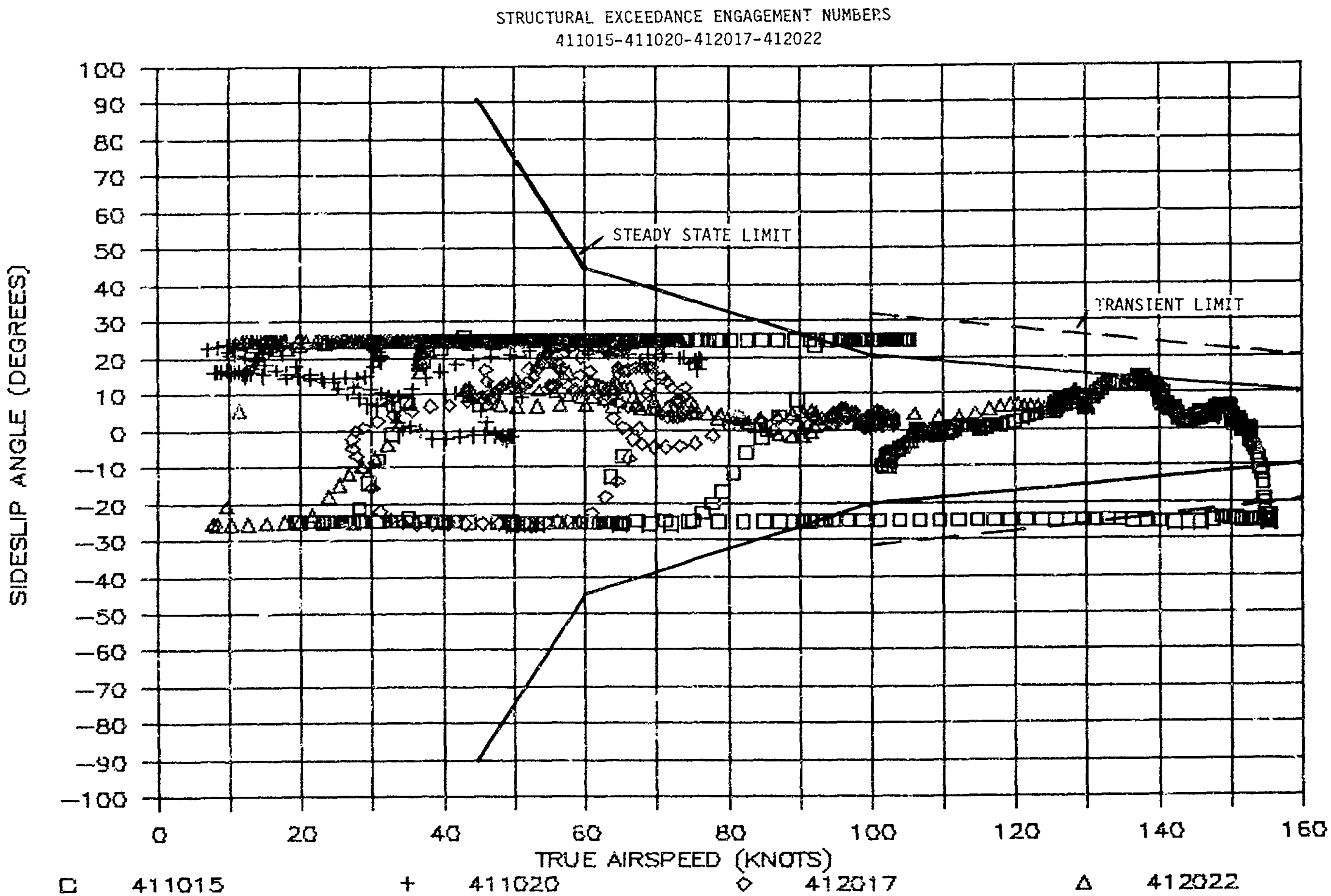


Figure 52. AH-64A sideslip angle vs airspeed data excursions during structural exceedance engagements.

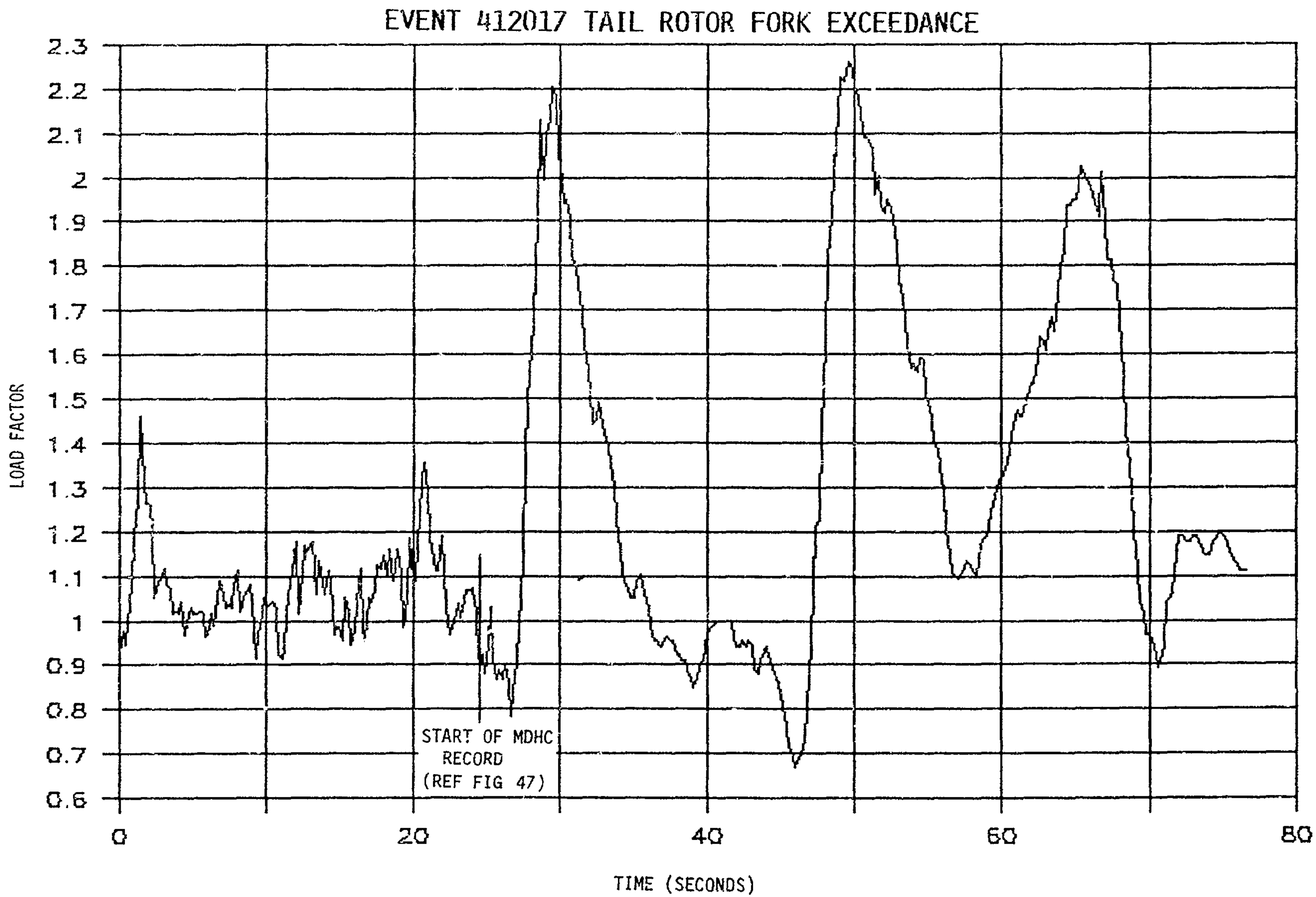


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage.

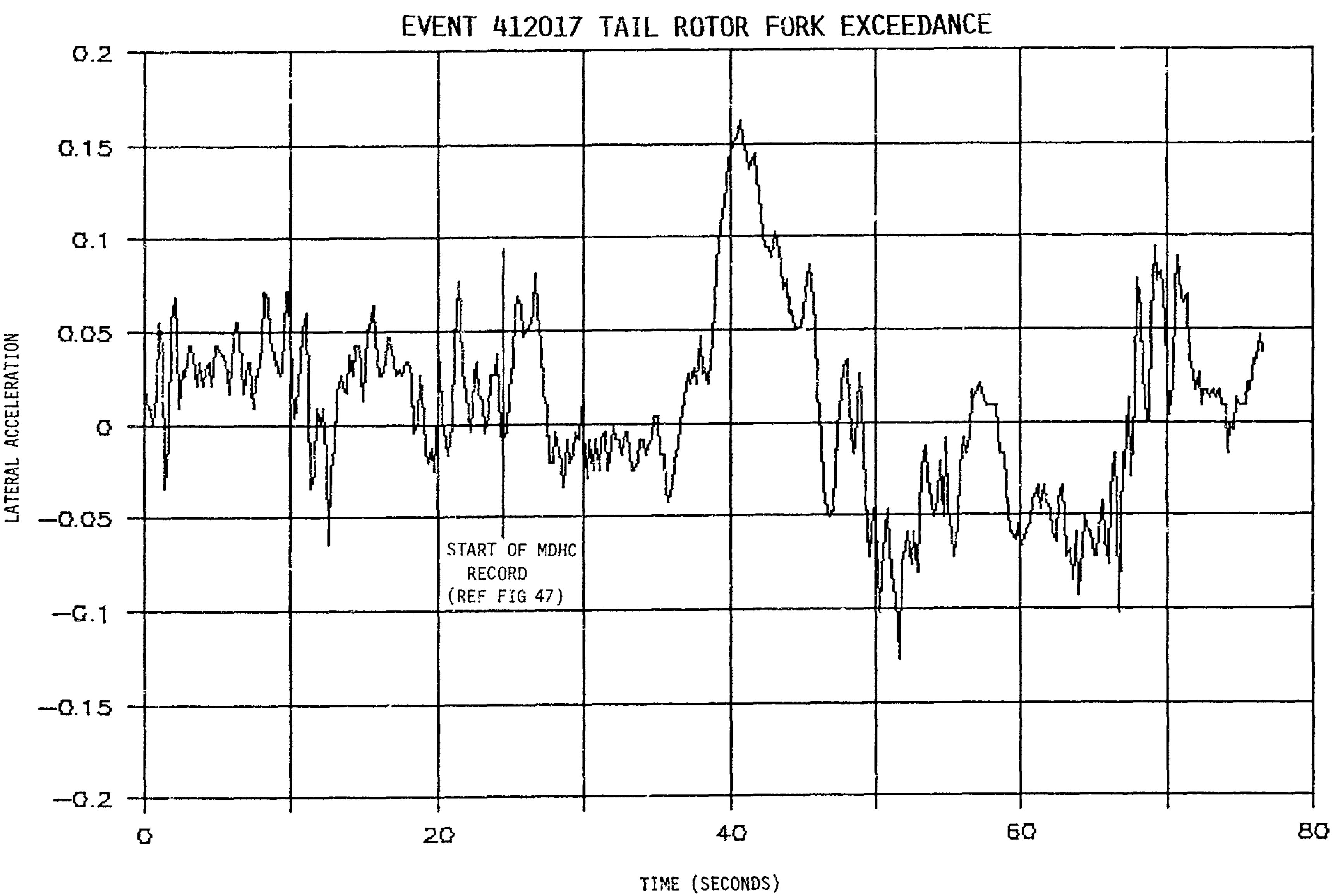


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

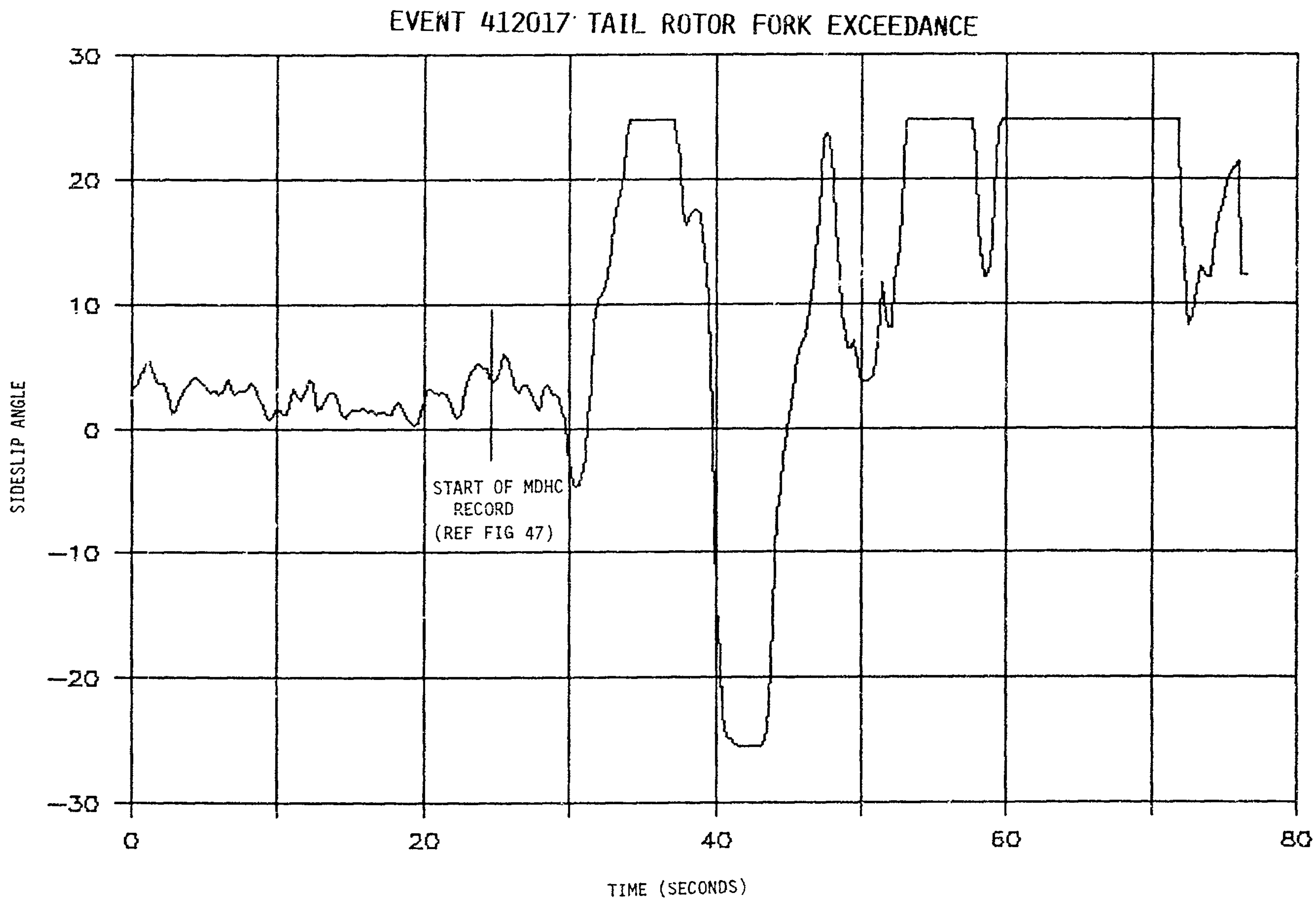


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage.
(Continued)

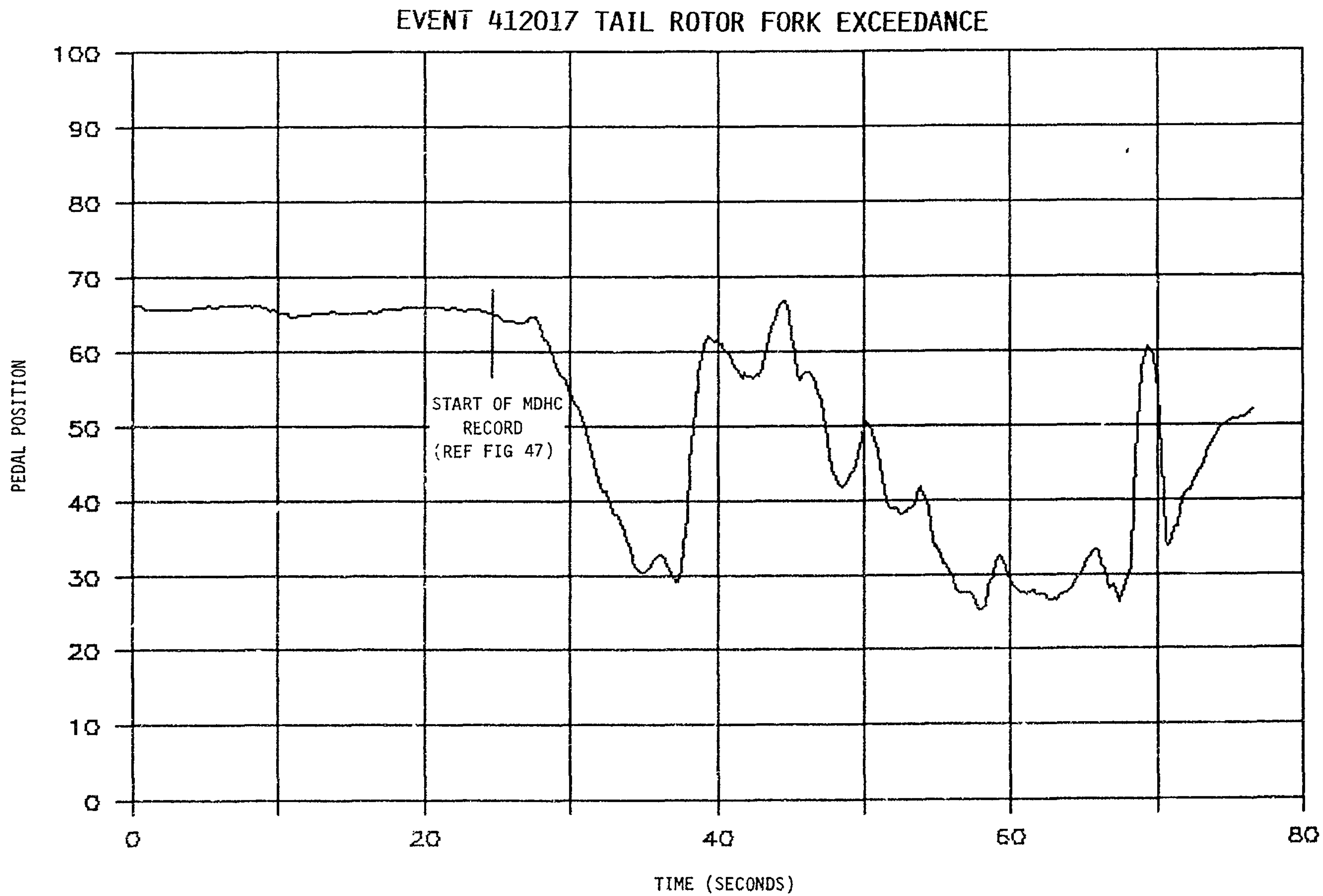


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

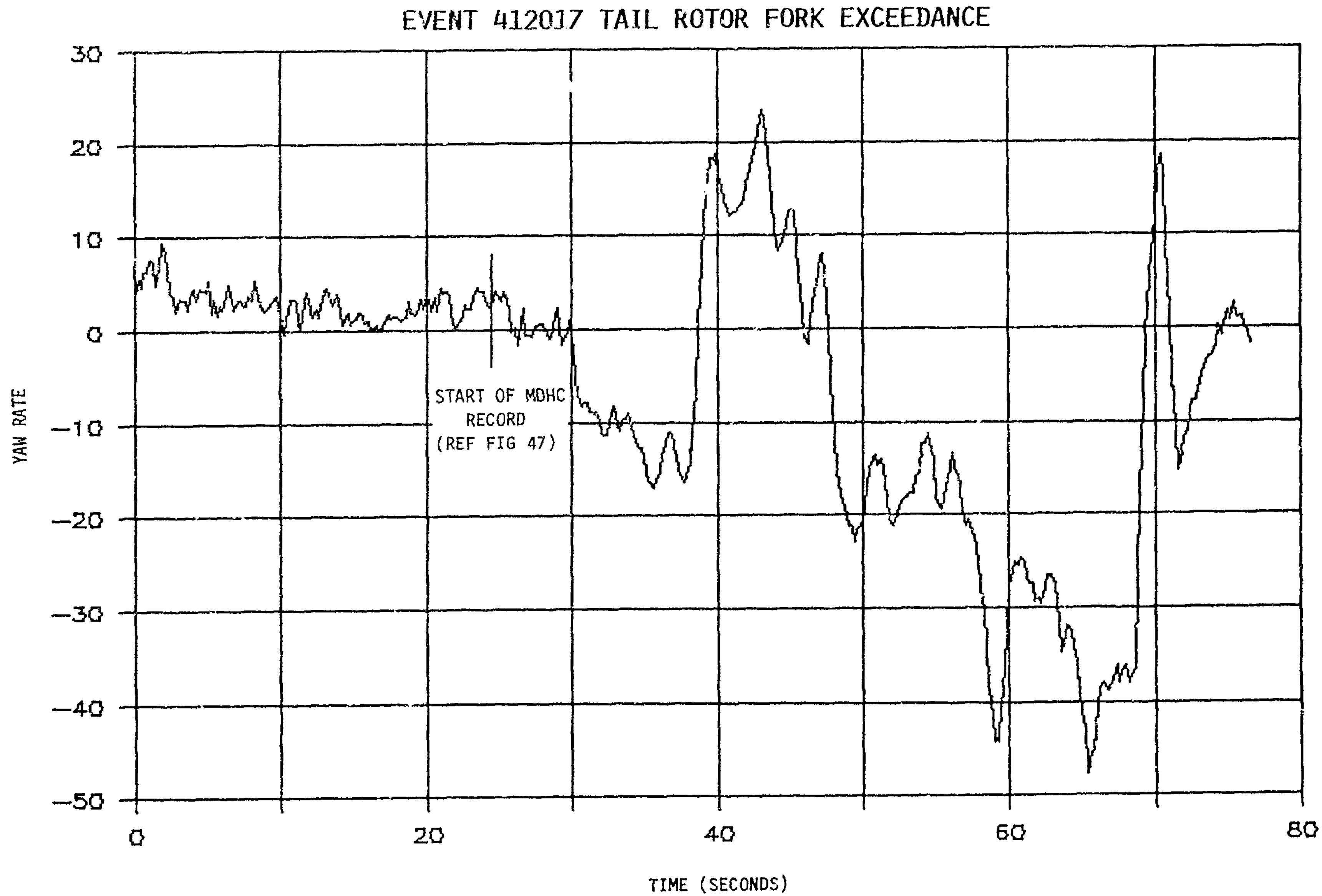


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

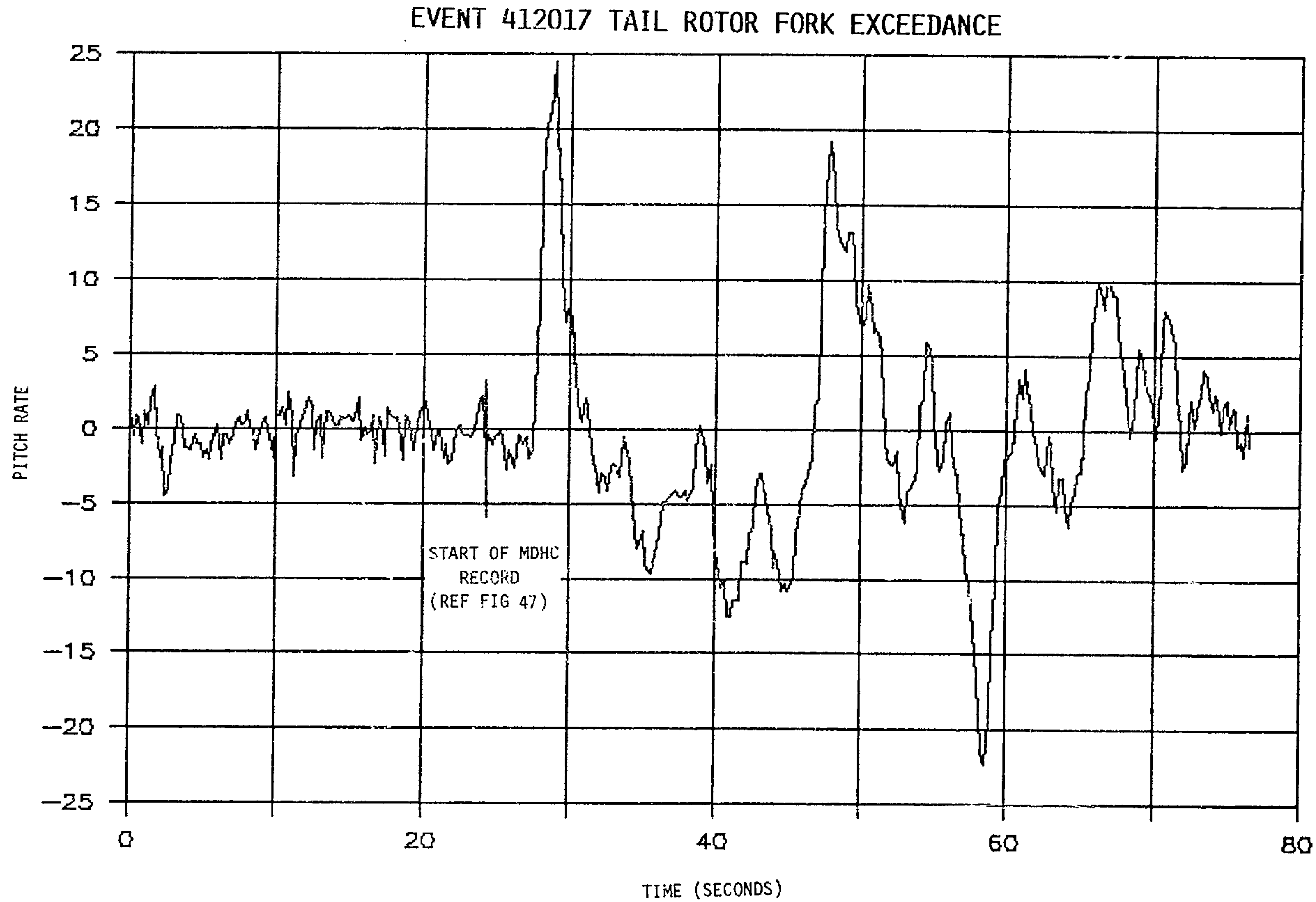


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

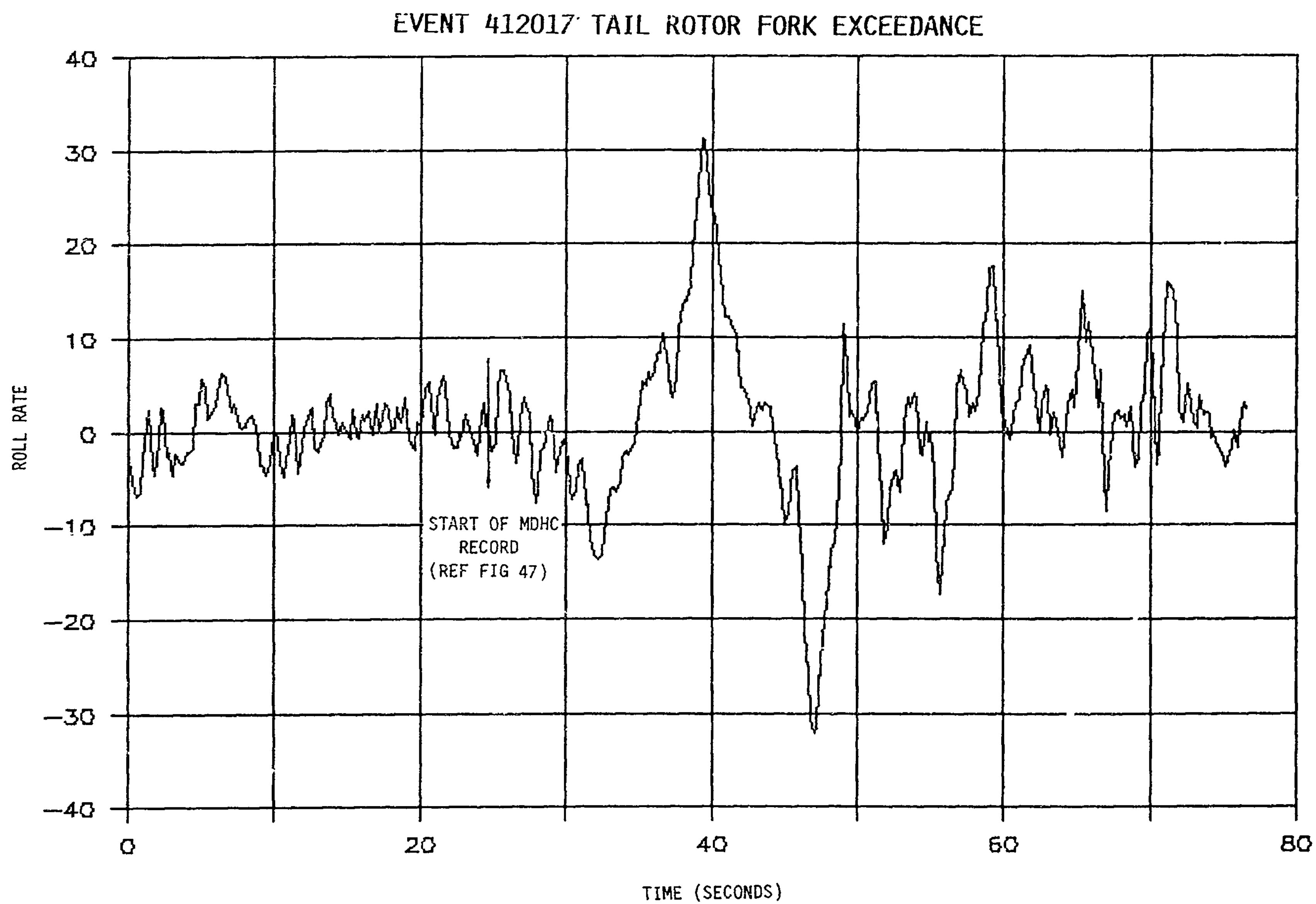


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

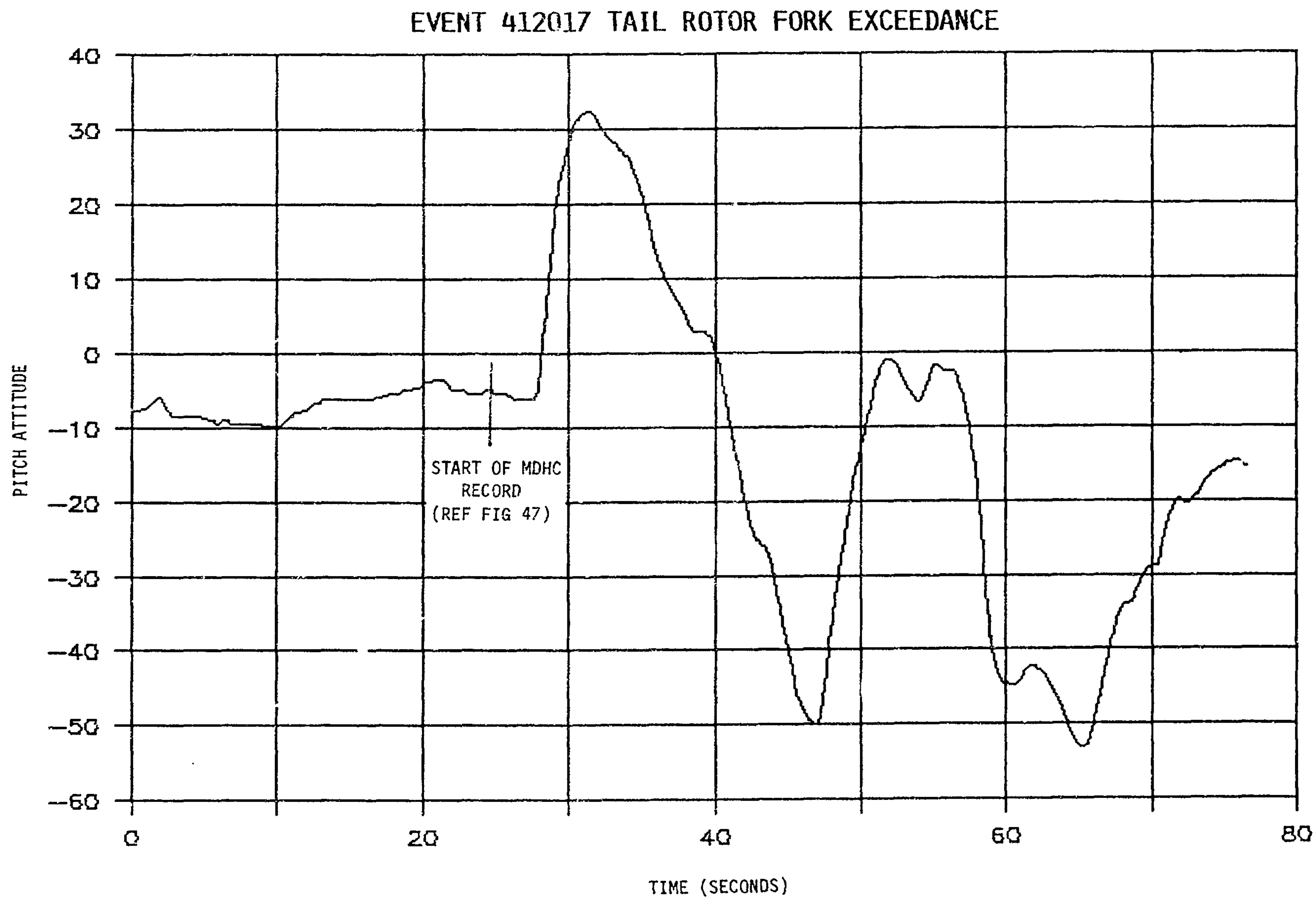


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

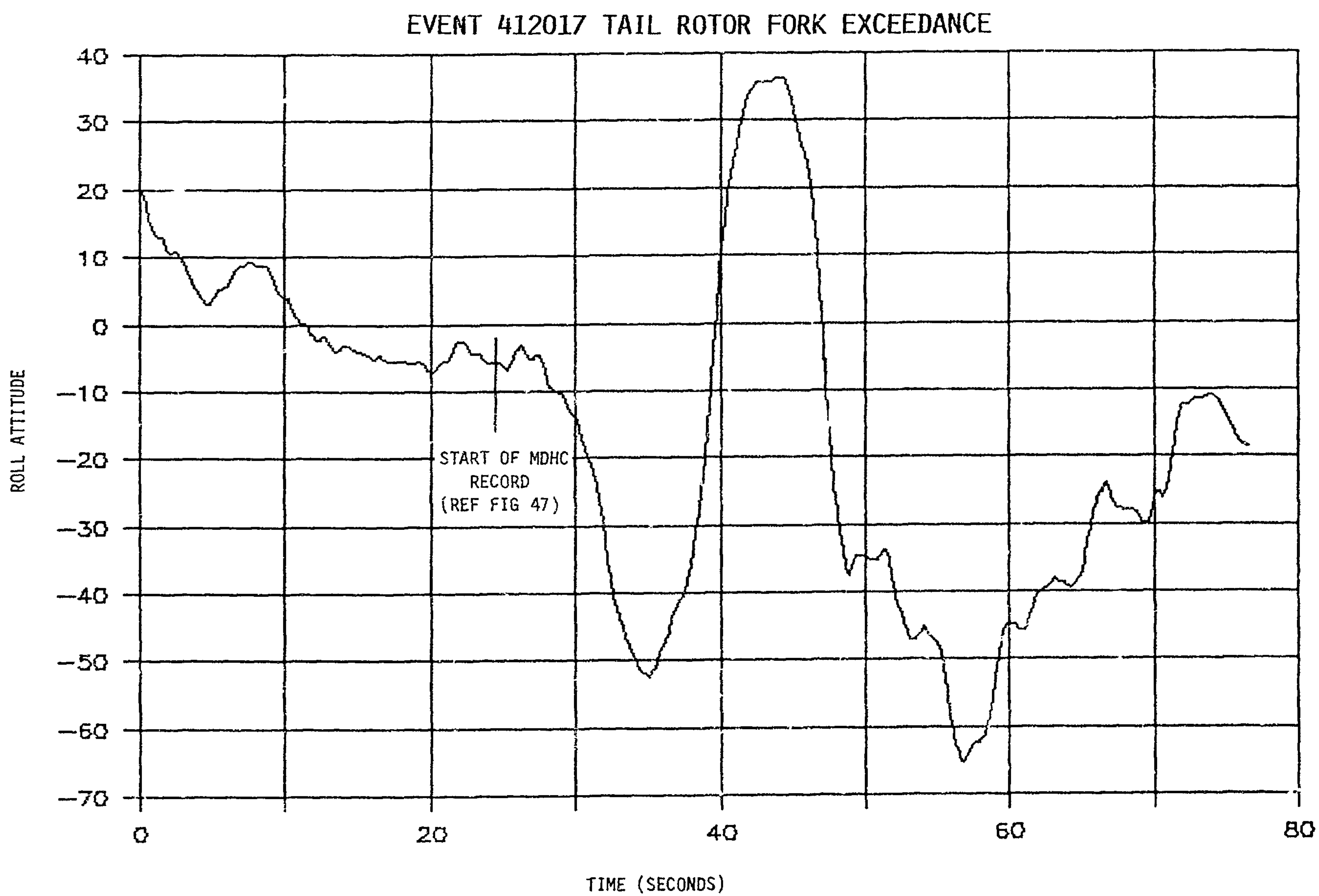


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

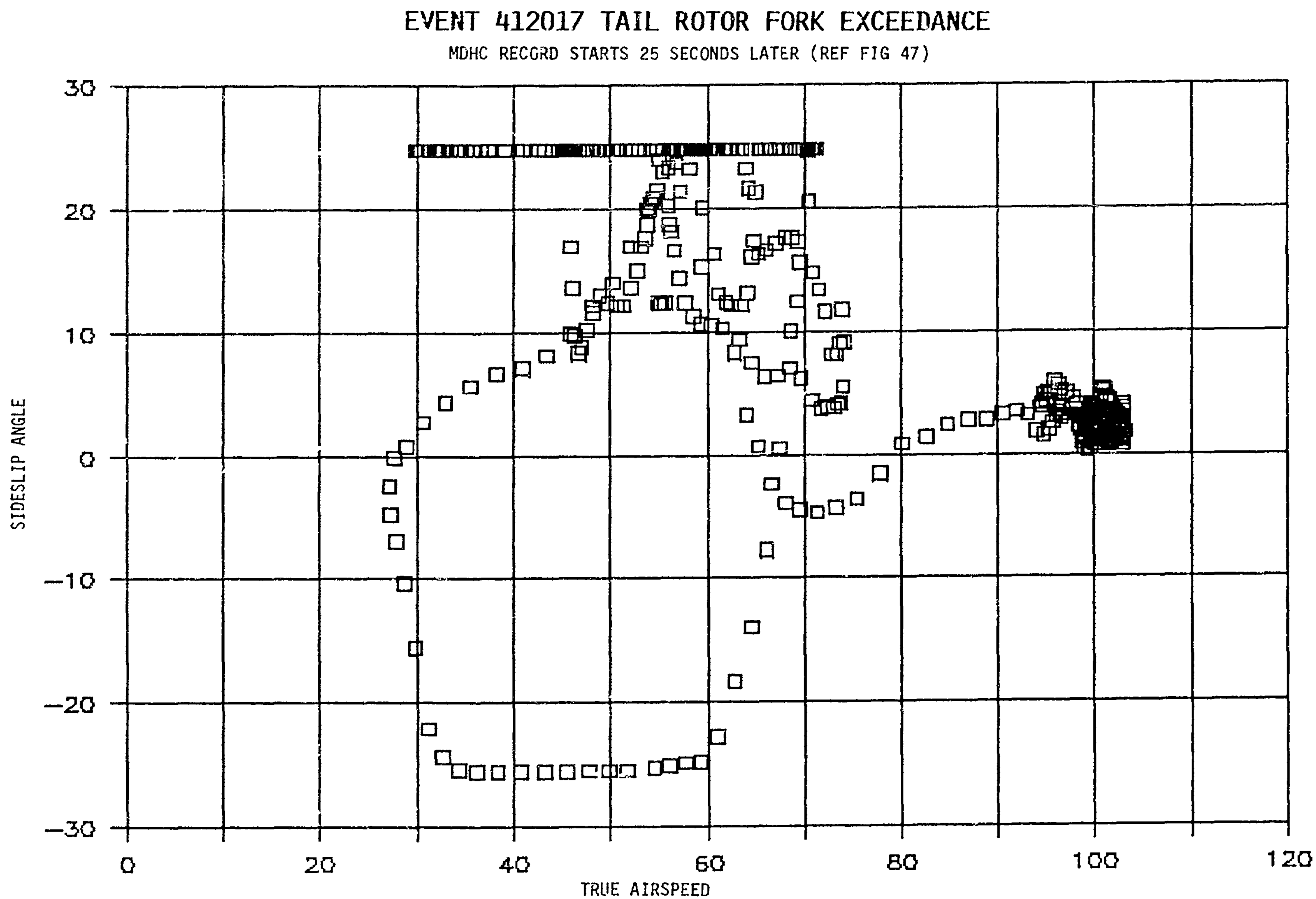


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Continued)

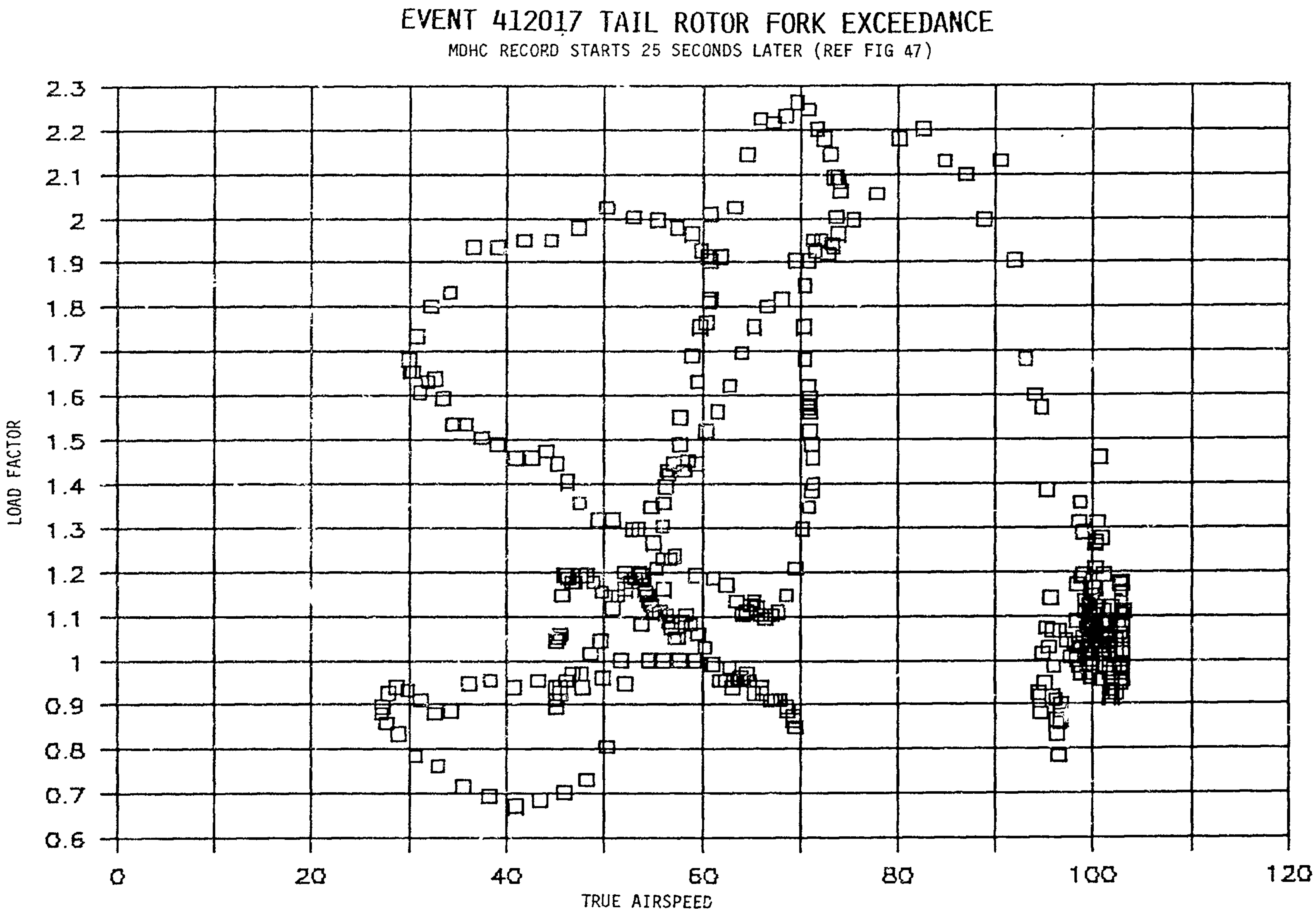


Figure 53. AH-64A state parameter time histories during tail rotor fork fatigue damage. (Concluded)

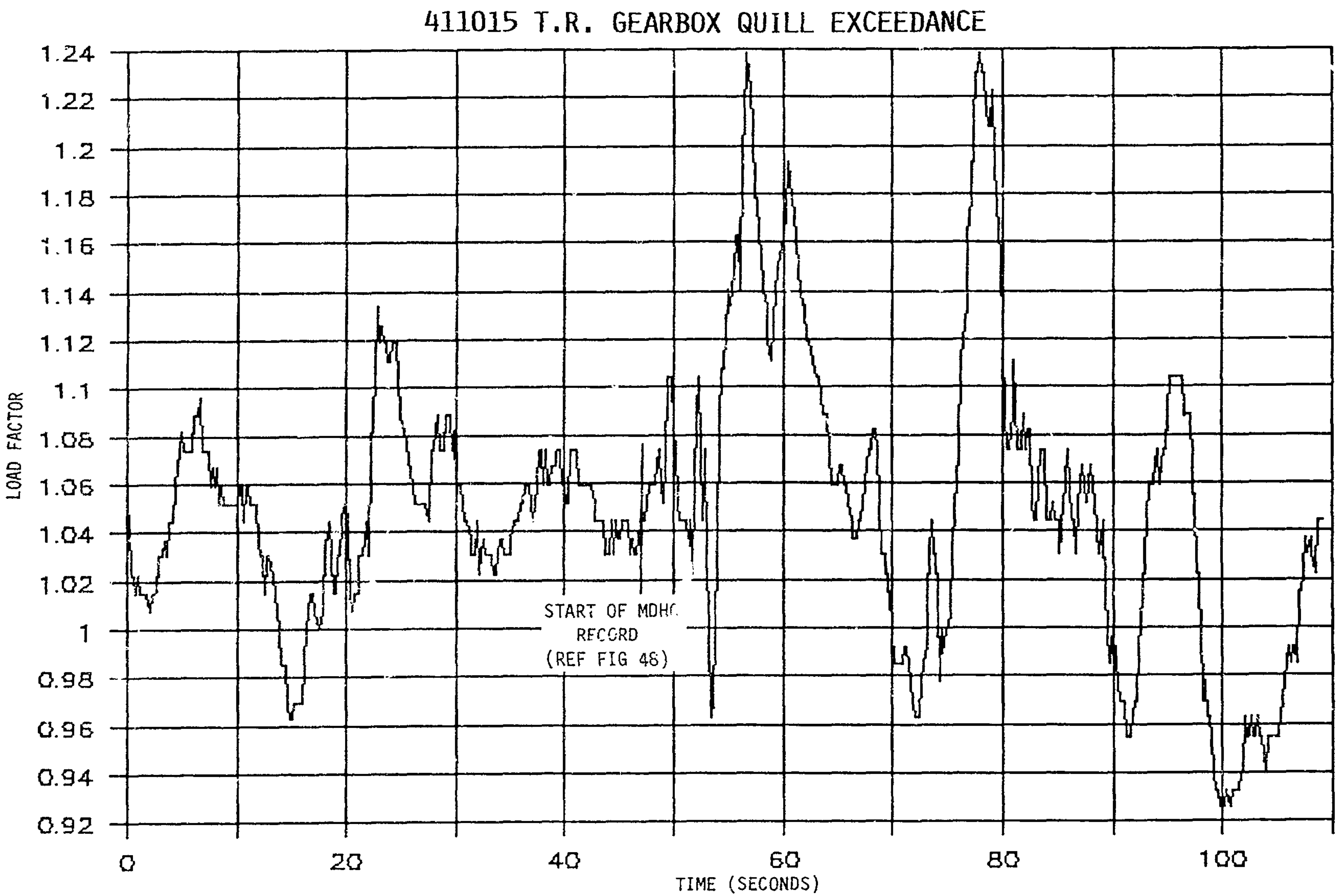


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage.

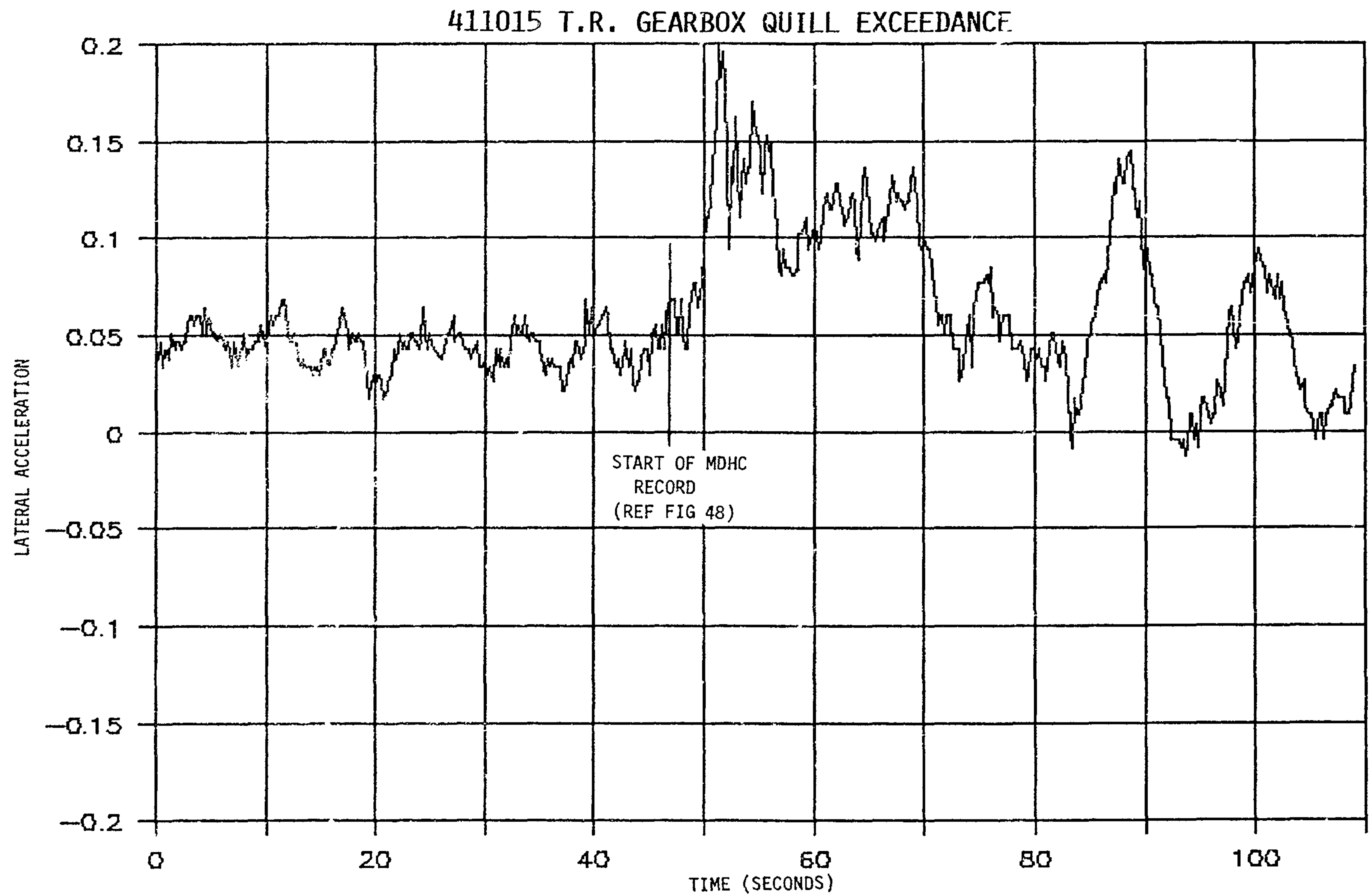


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

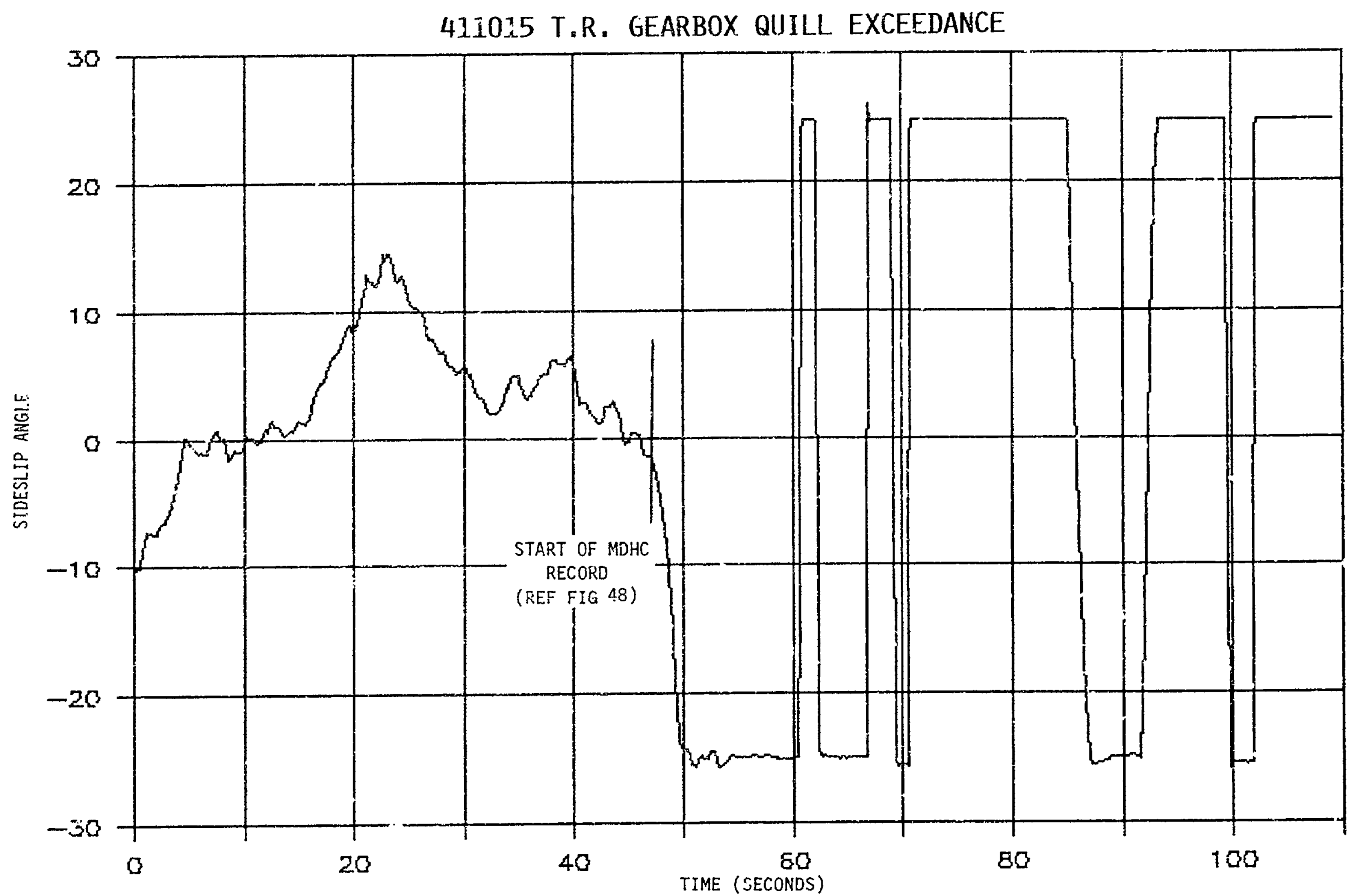


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

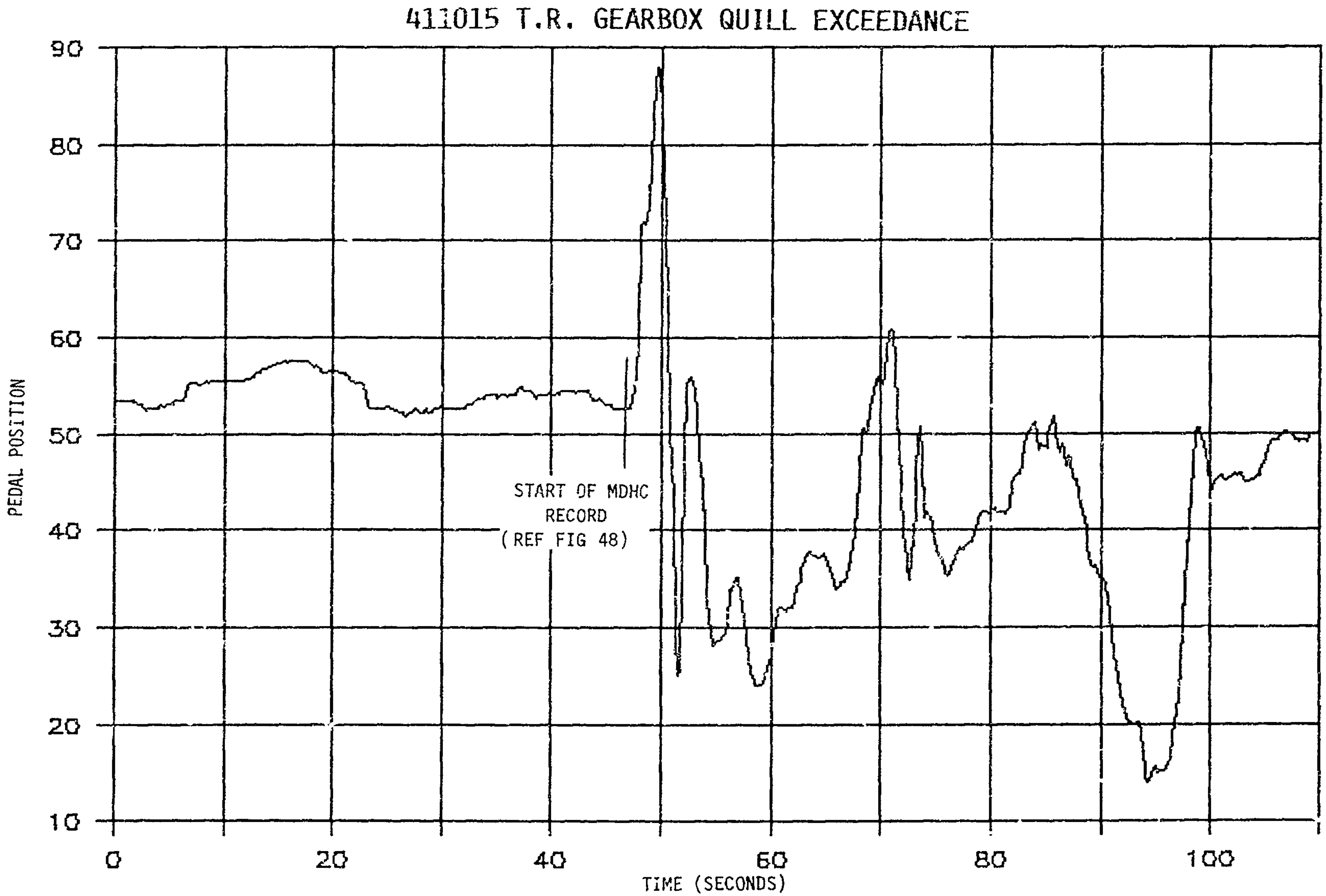


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

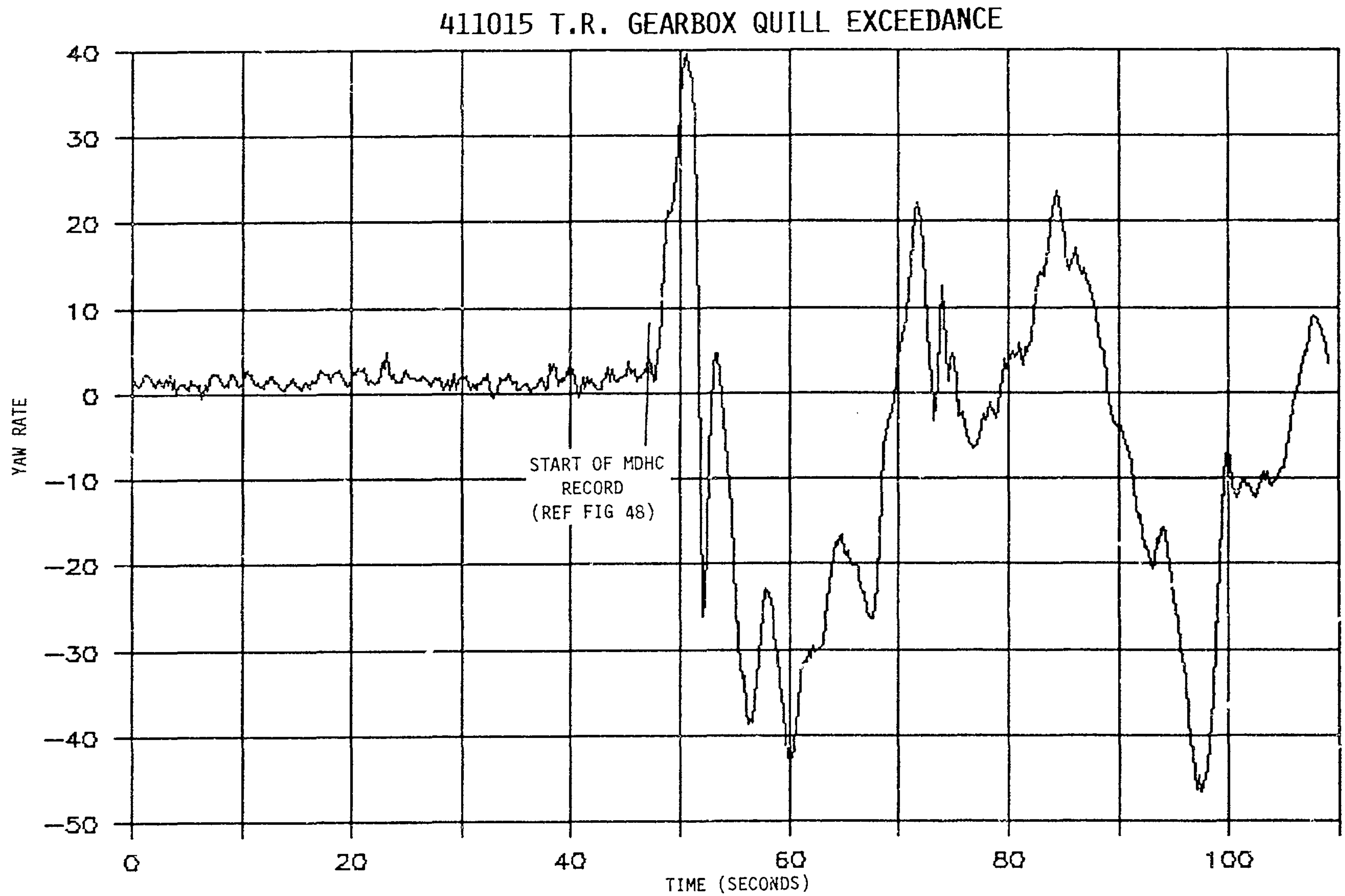


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

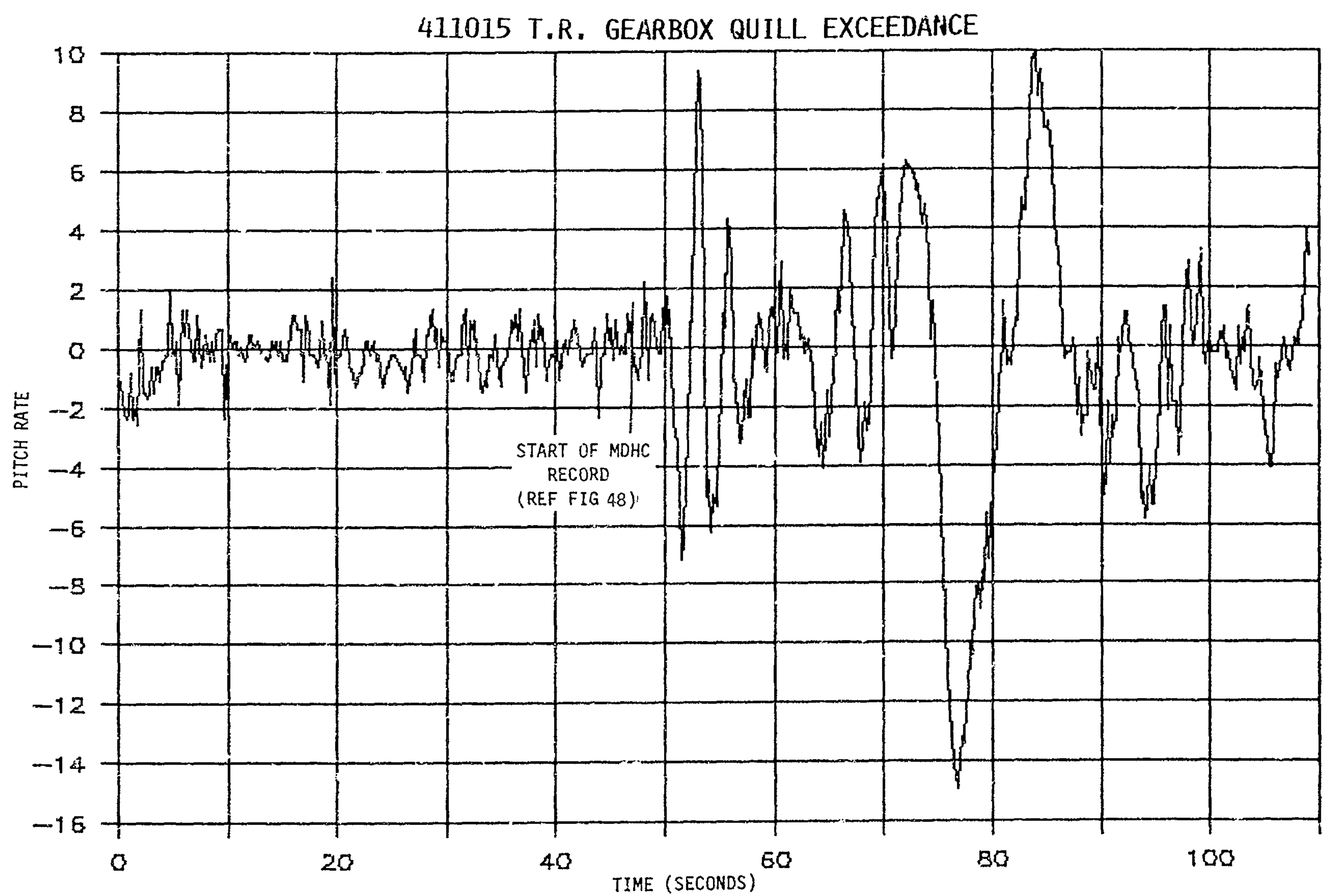


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

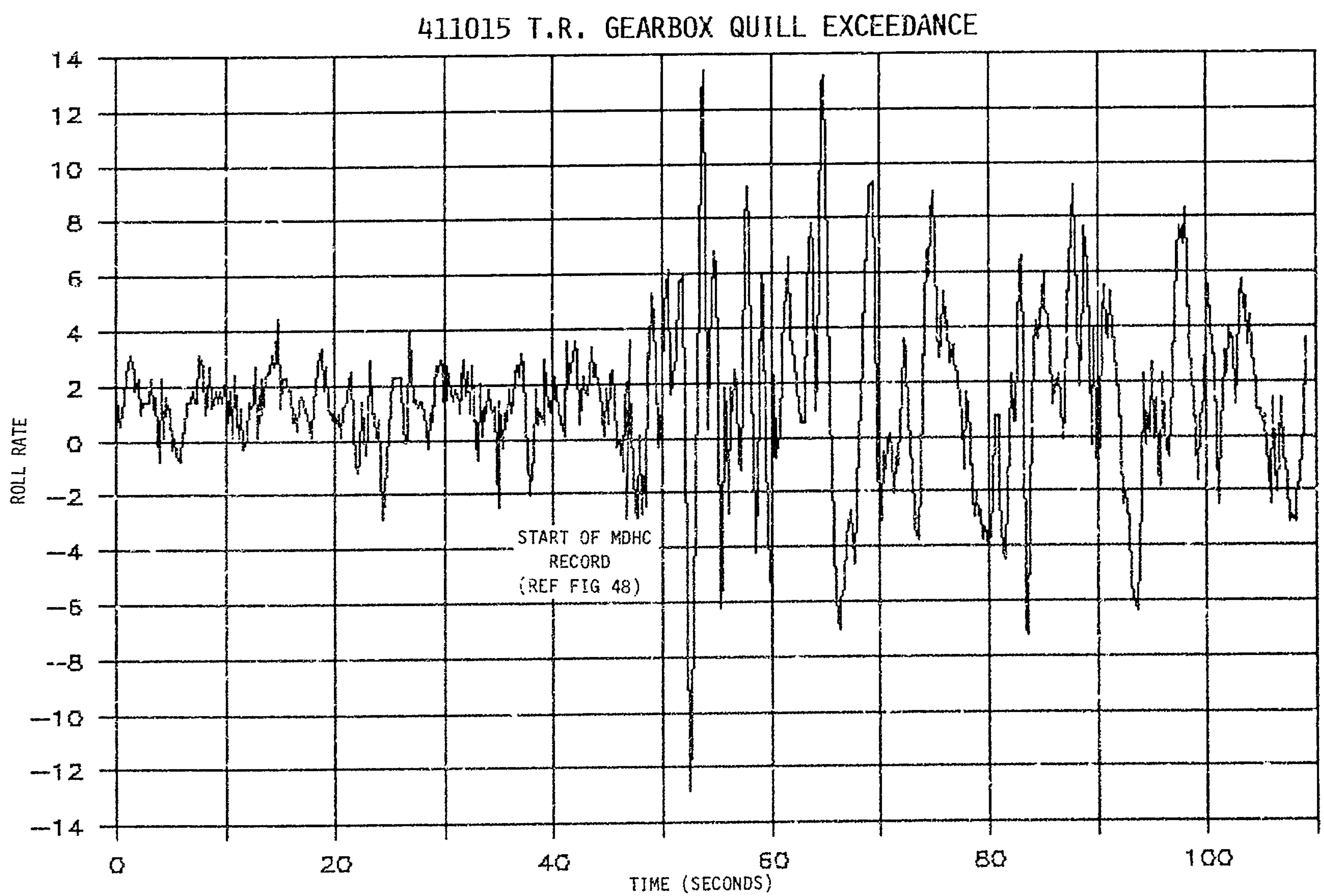


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

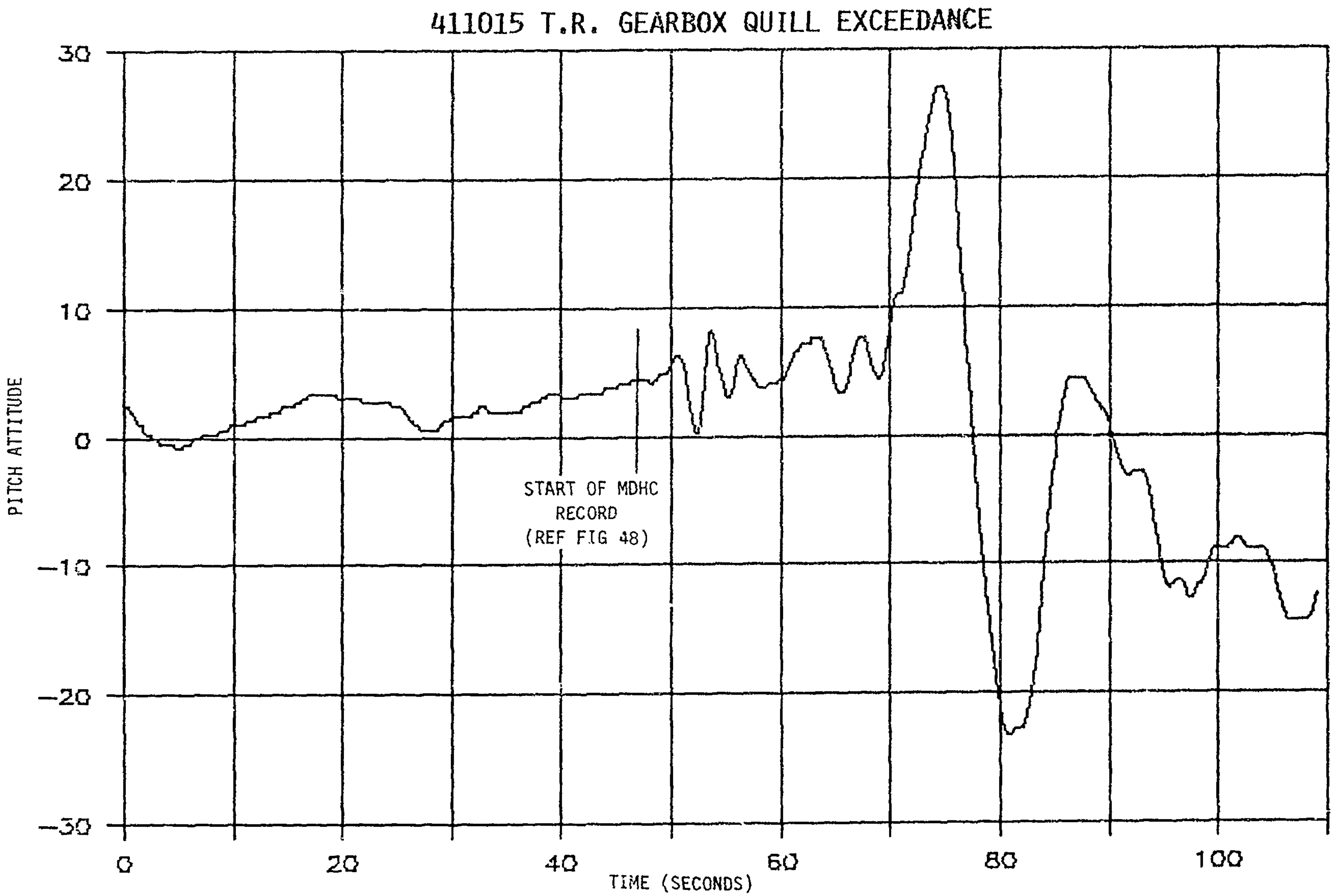


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

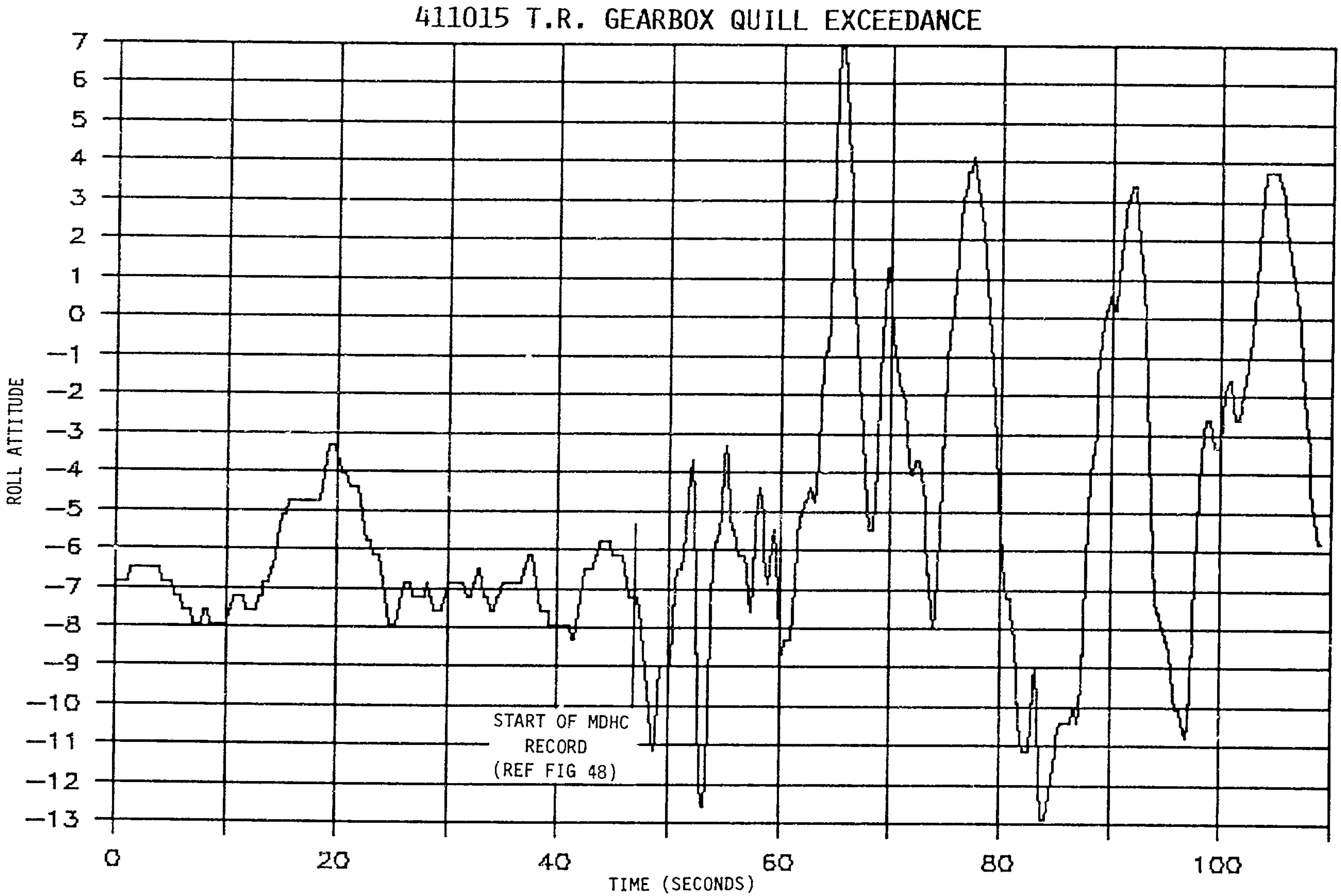


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

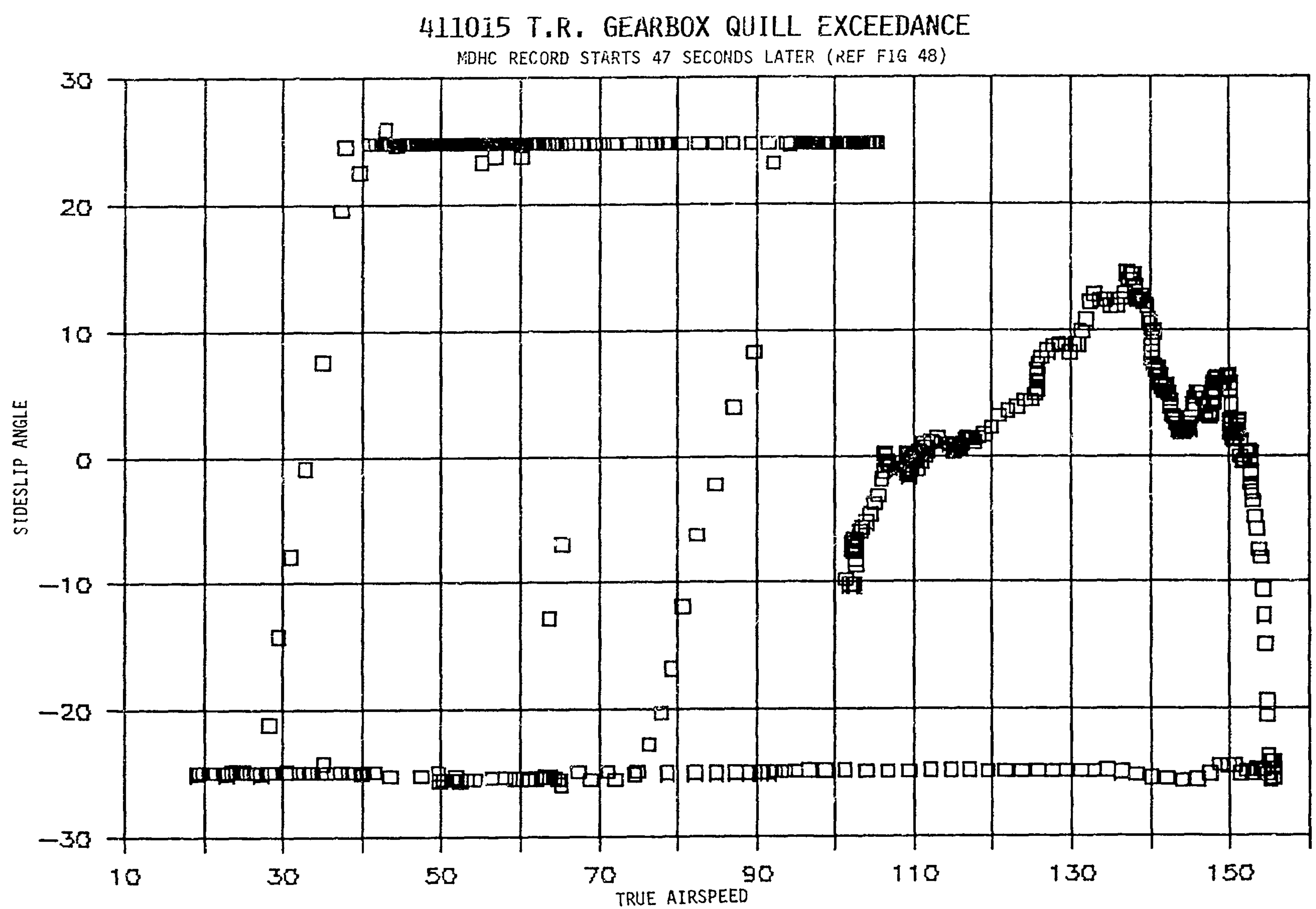


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

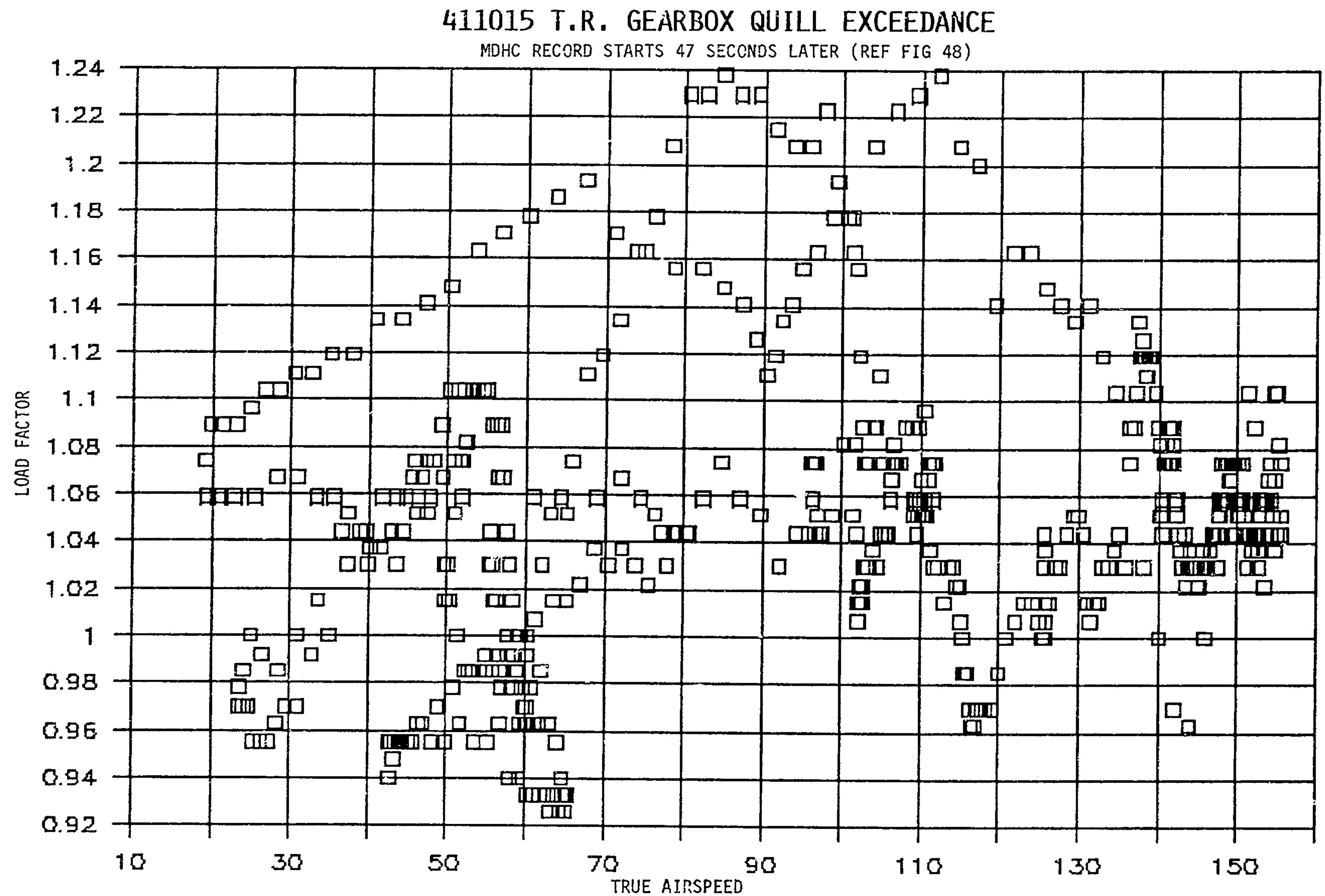


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Continued)

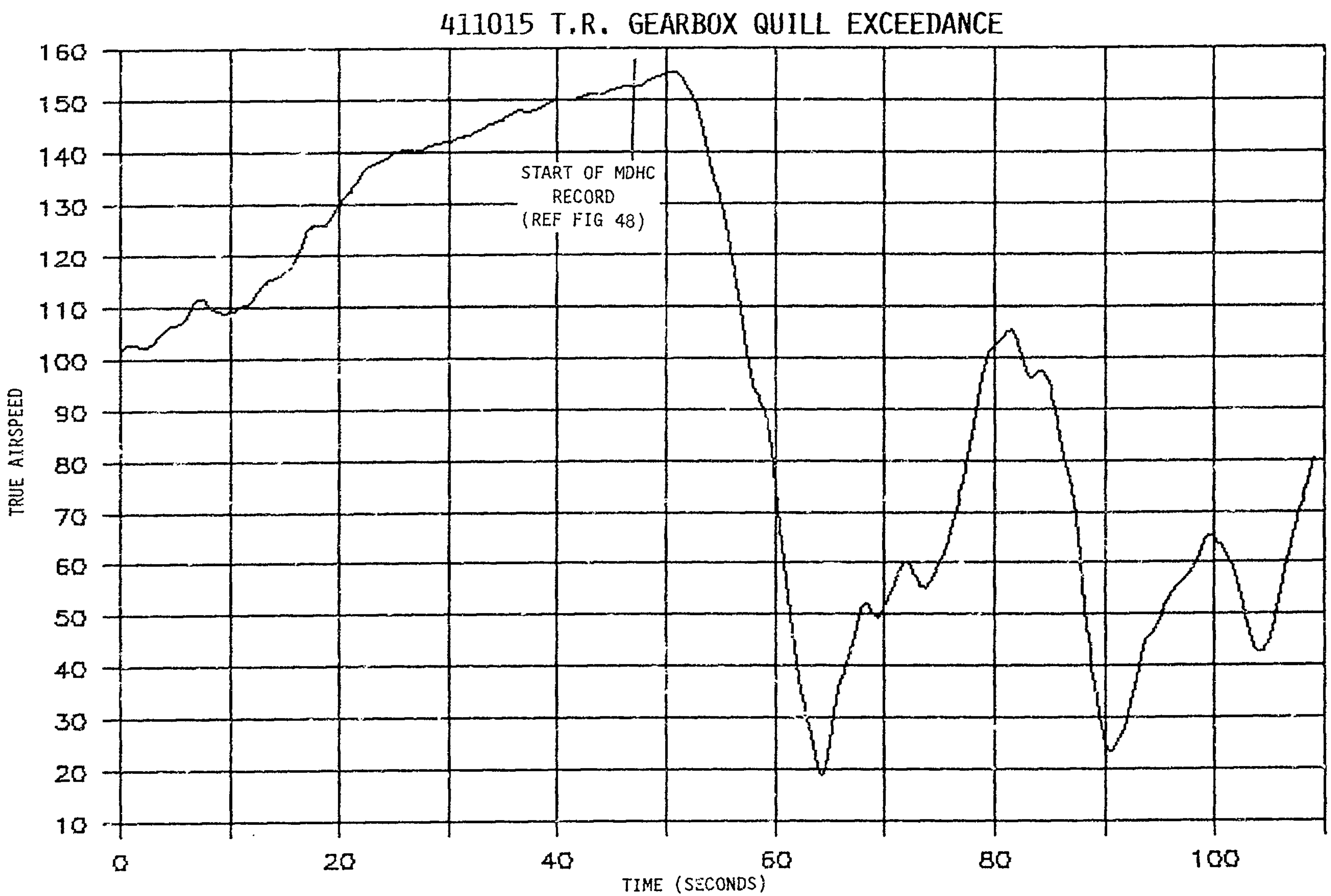


Figure 54. AH-64A state parameter time histories during tail rotor gearbox quill shaft fatigue damage. (Concluded)

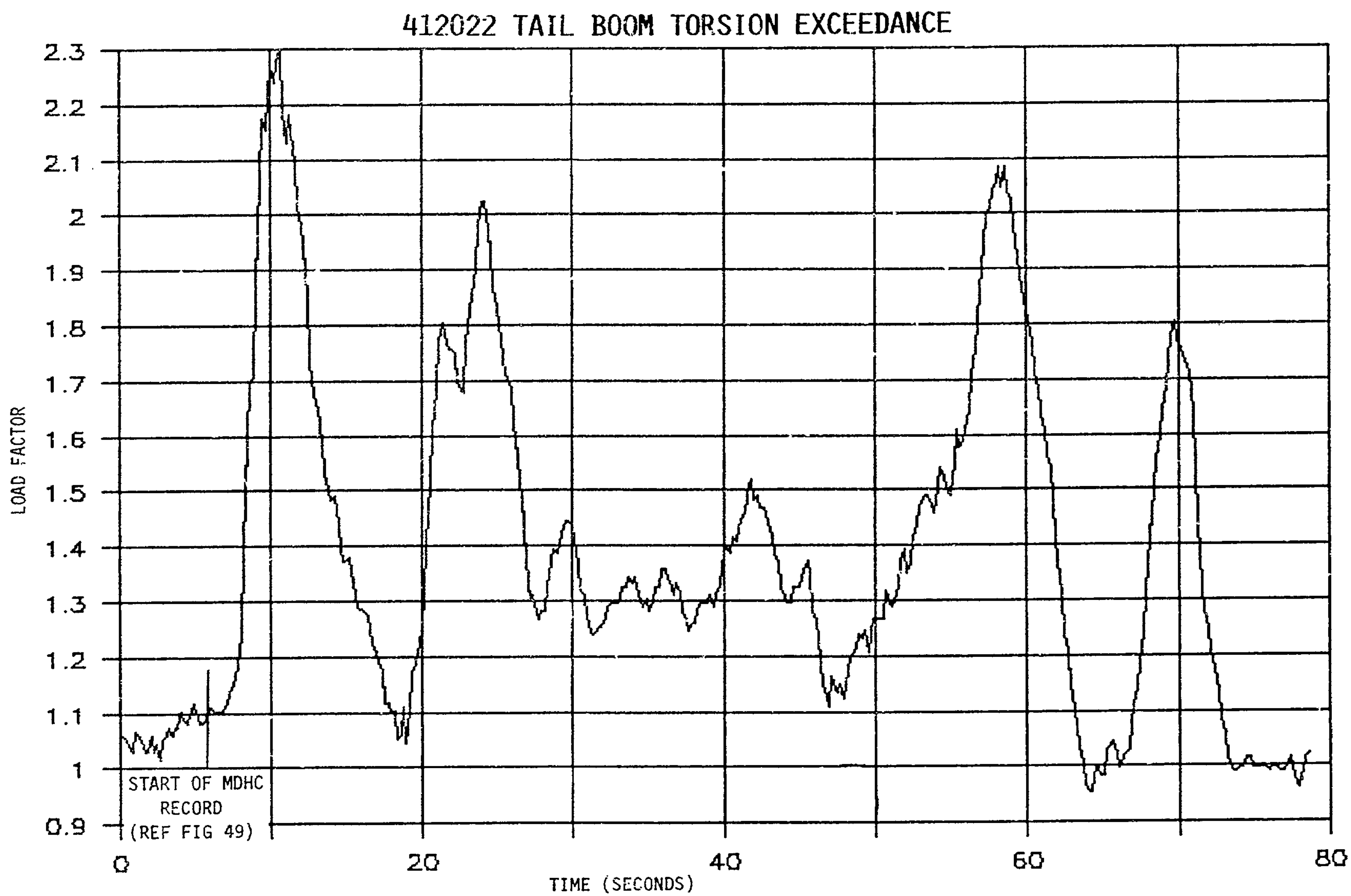


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage.

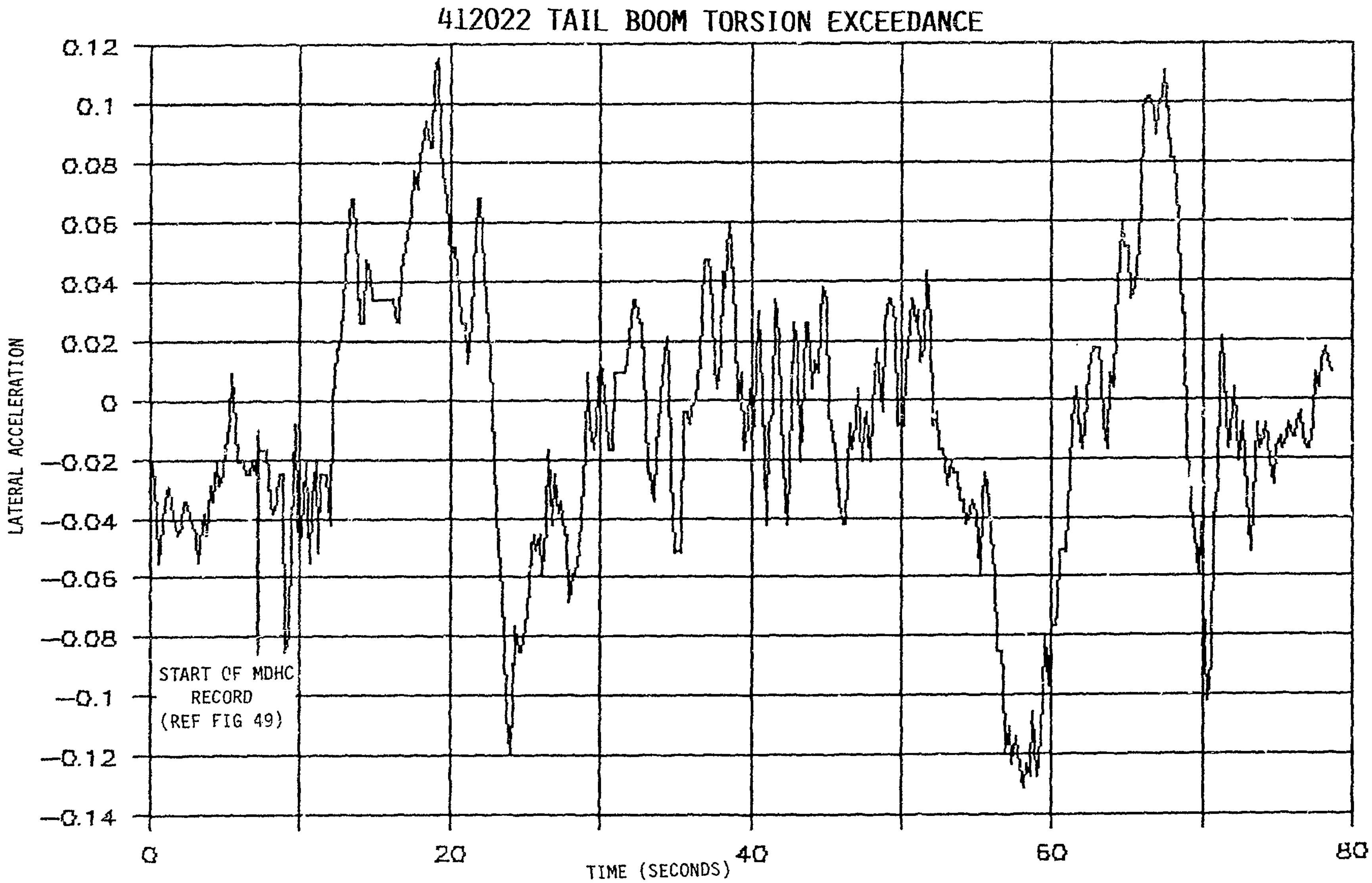


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

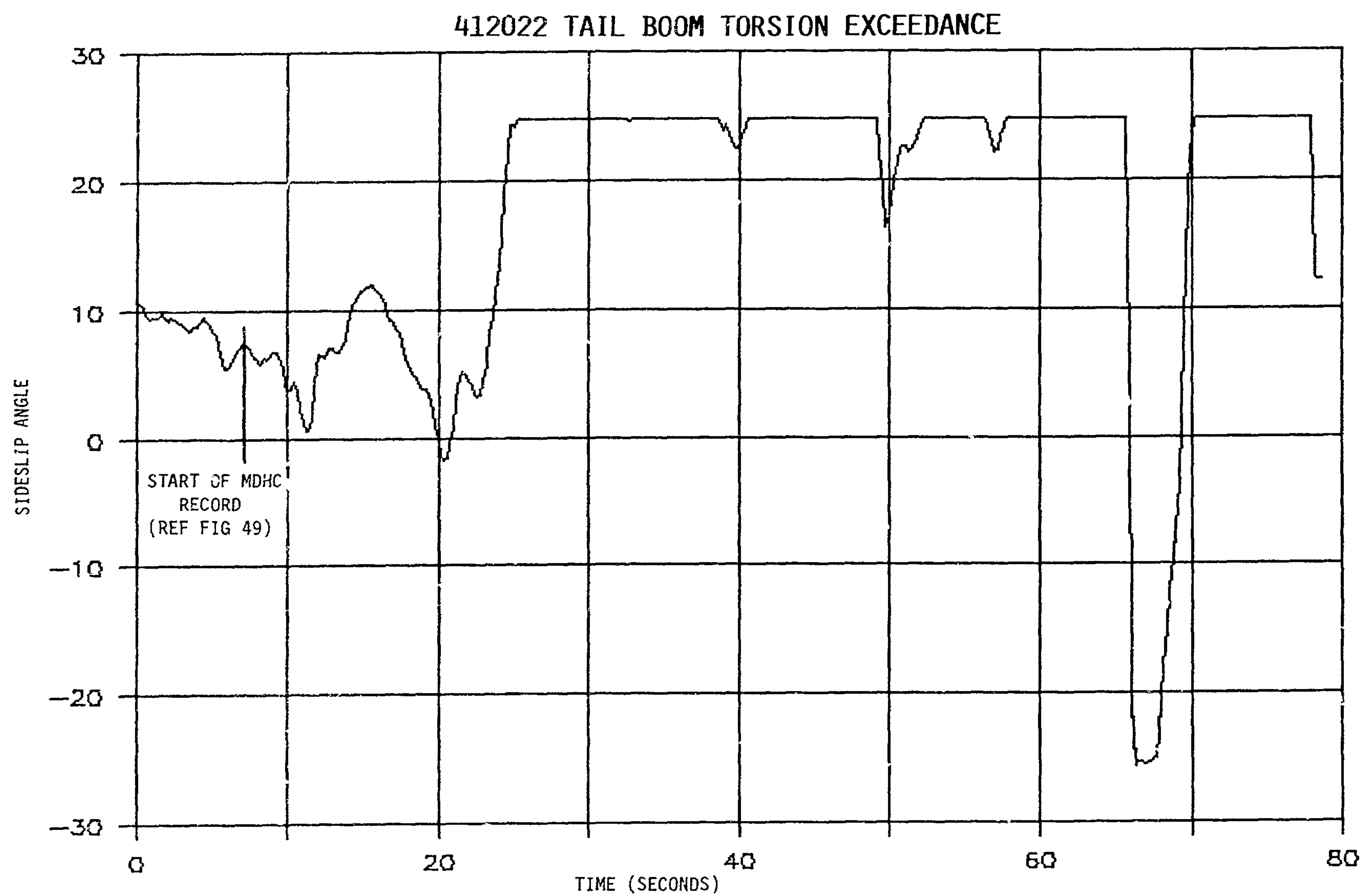


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

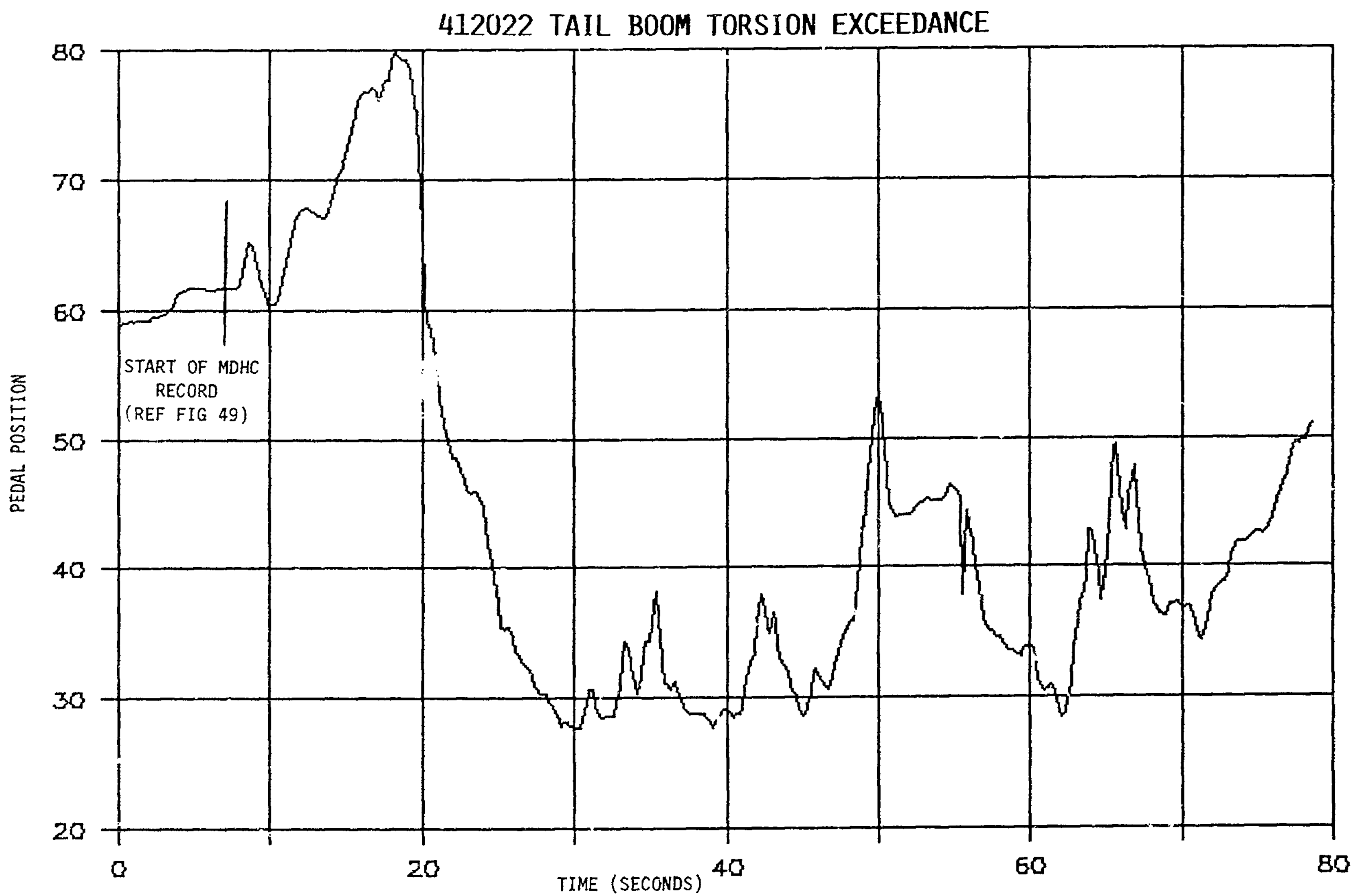


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

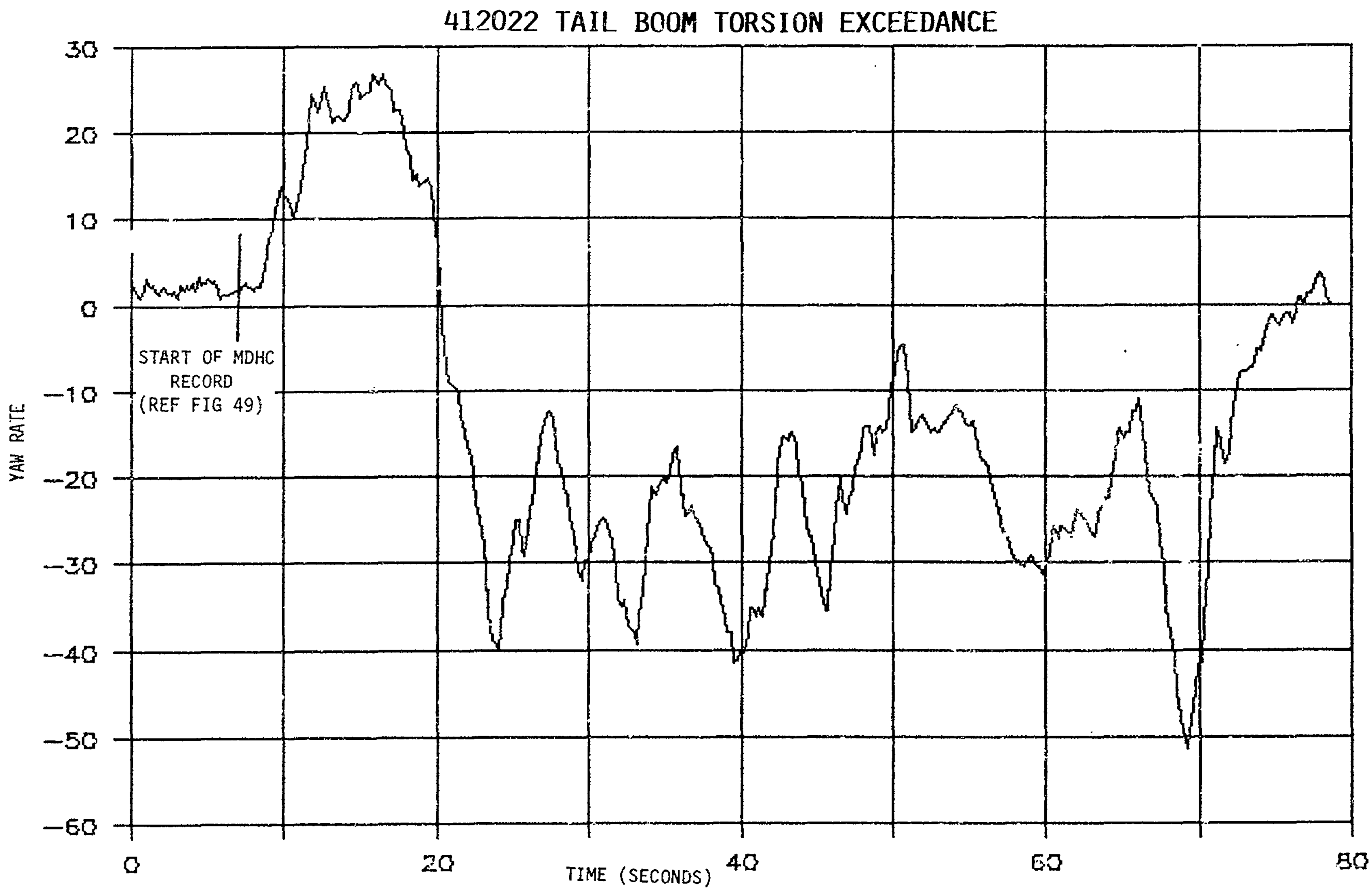


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

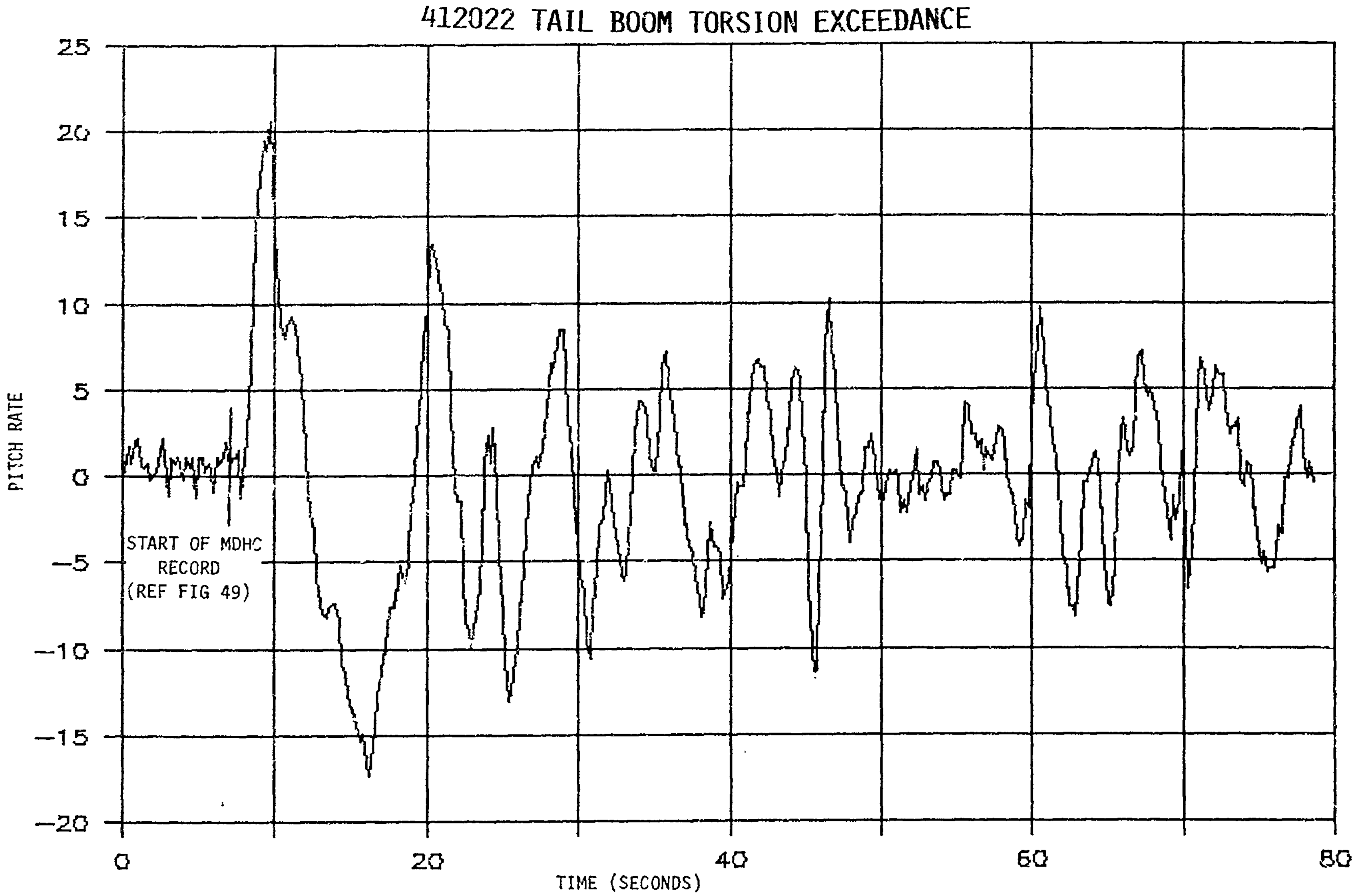


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

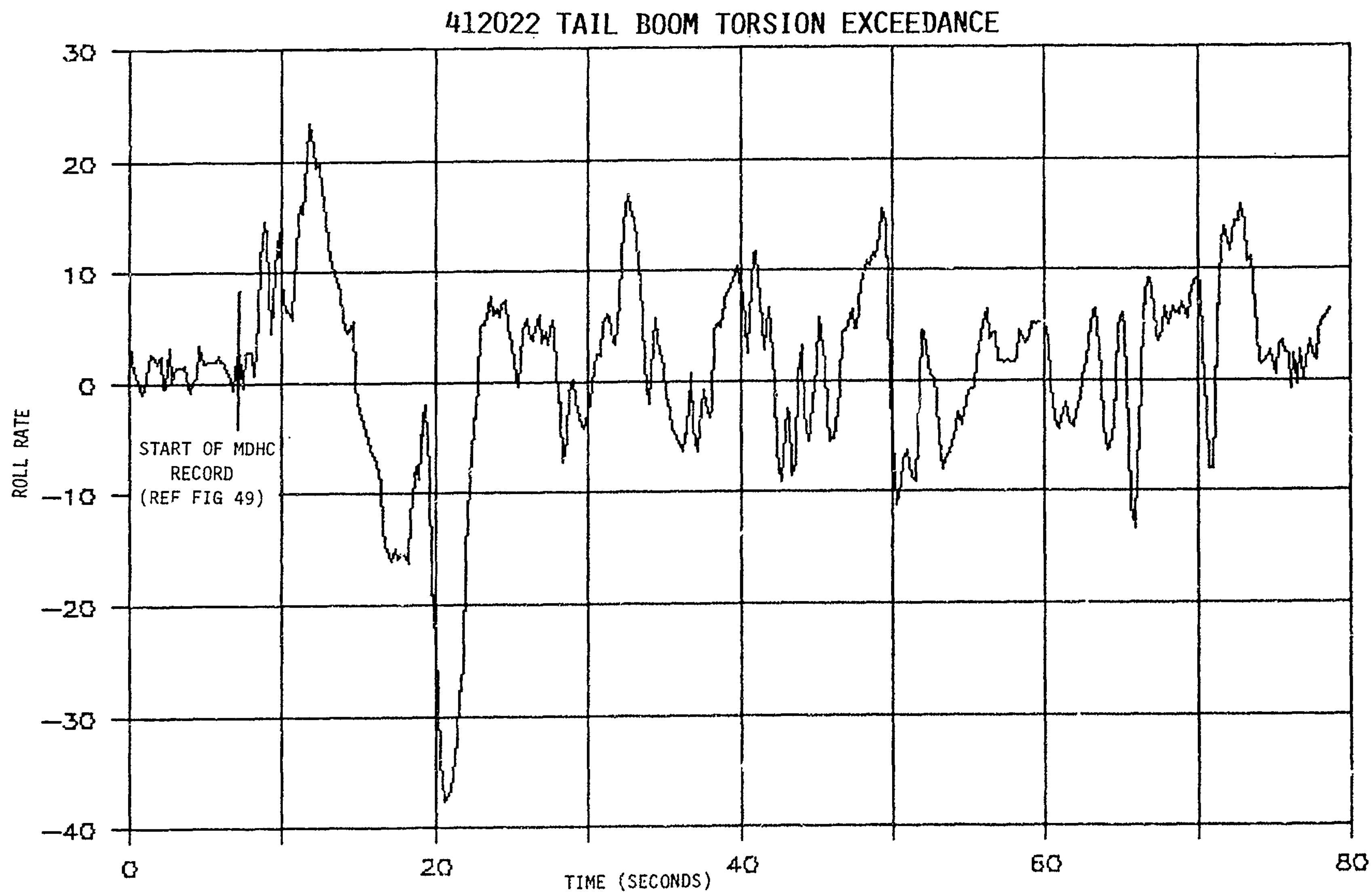


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

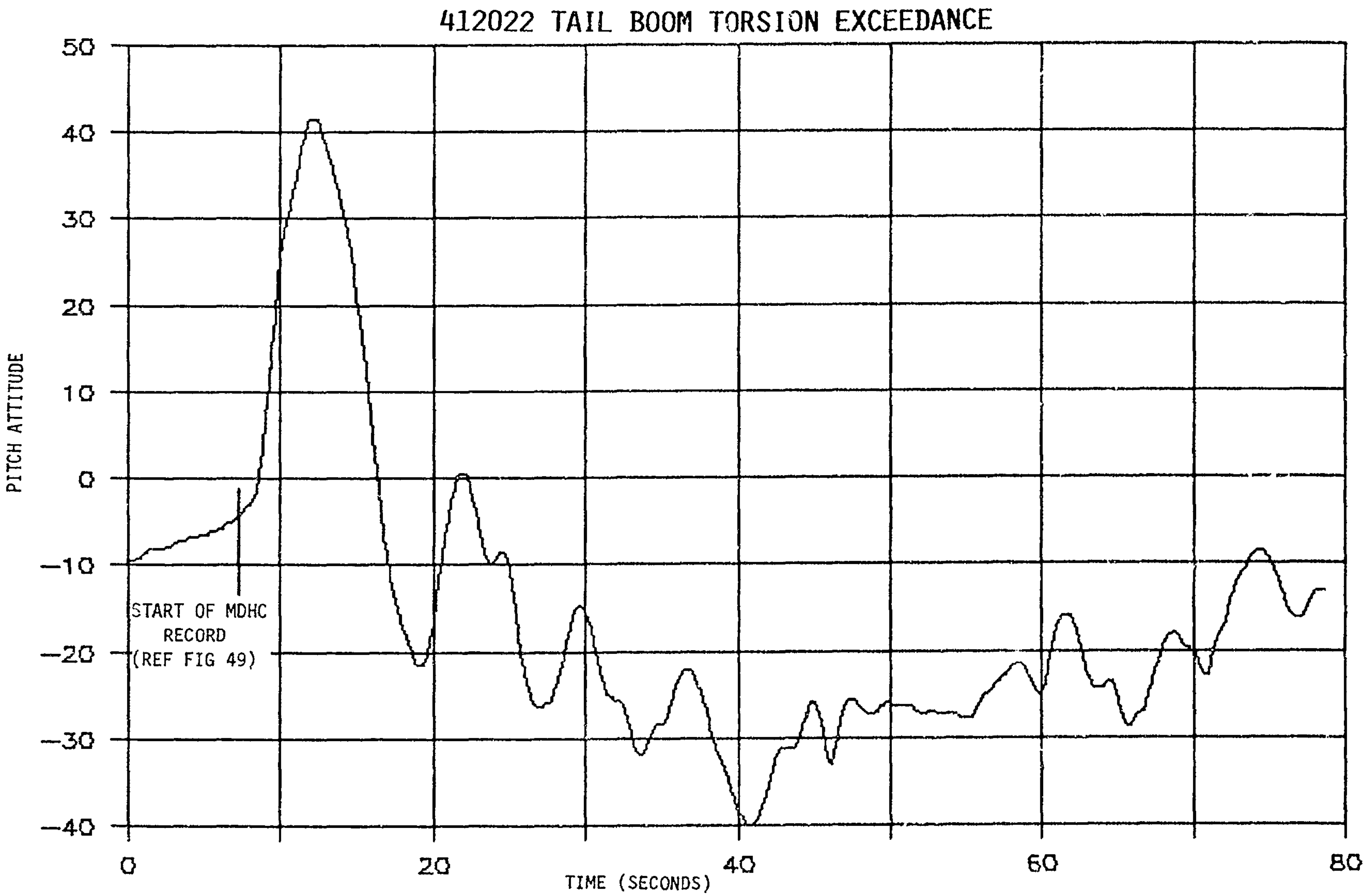


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

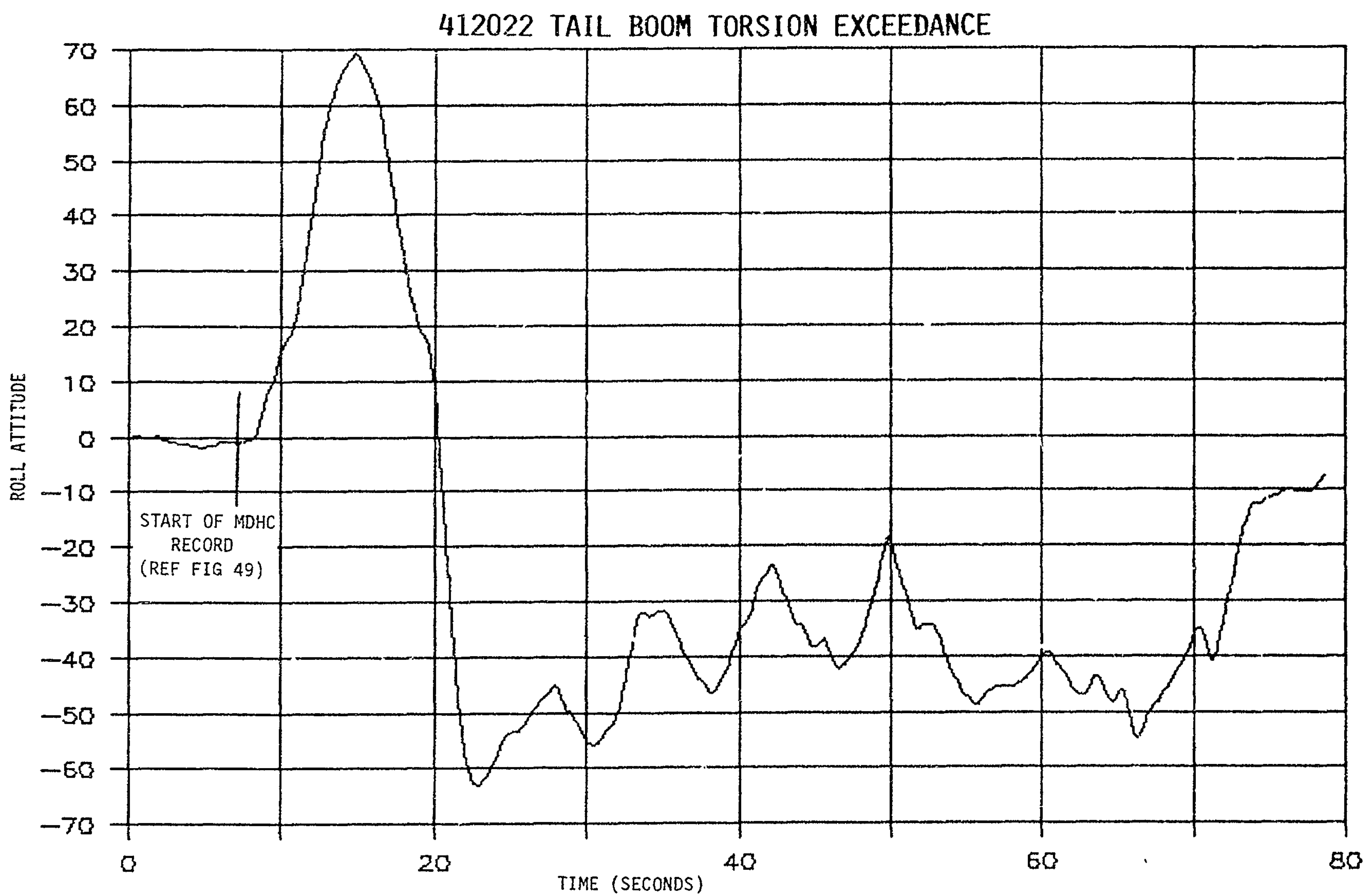


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

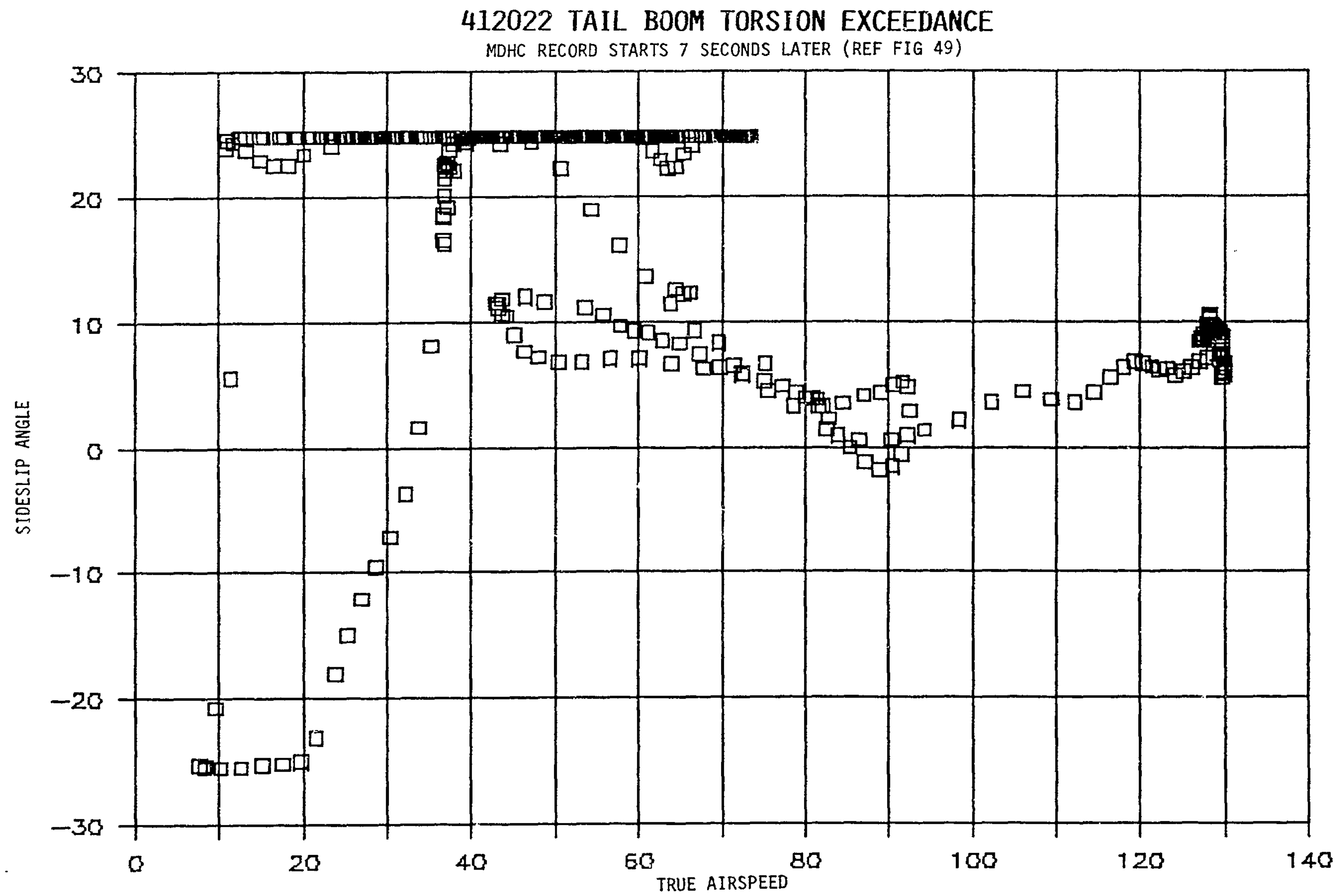


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

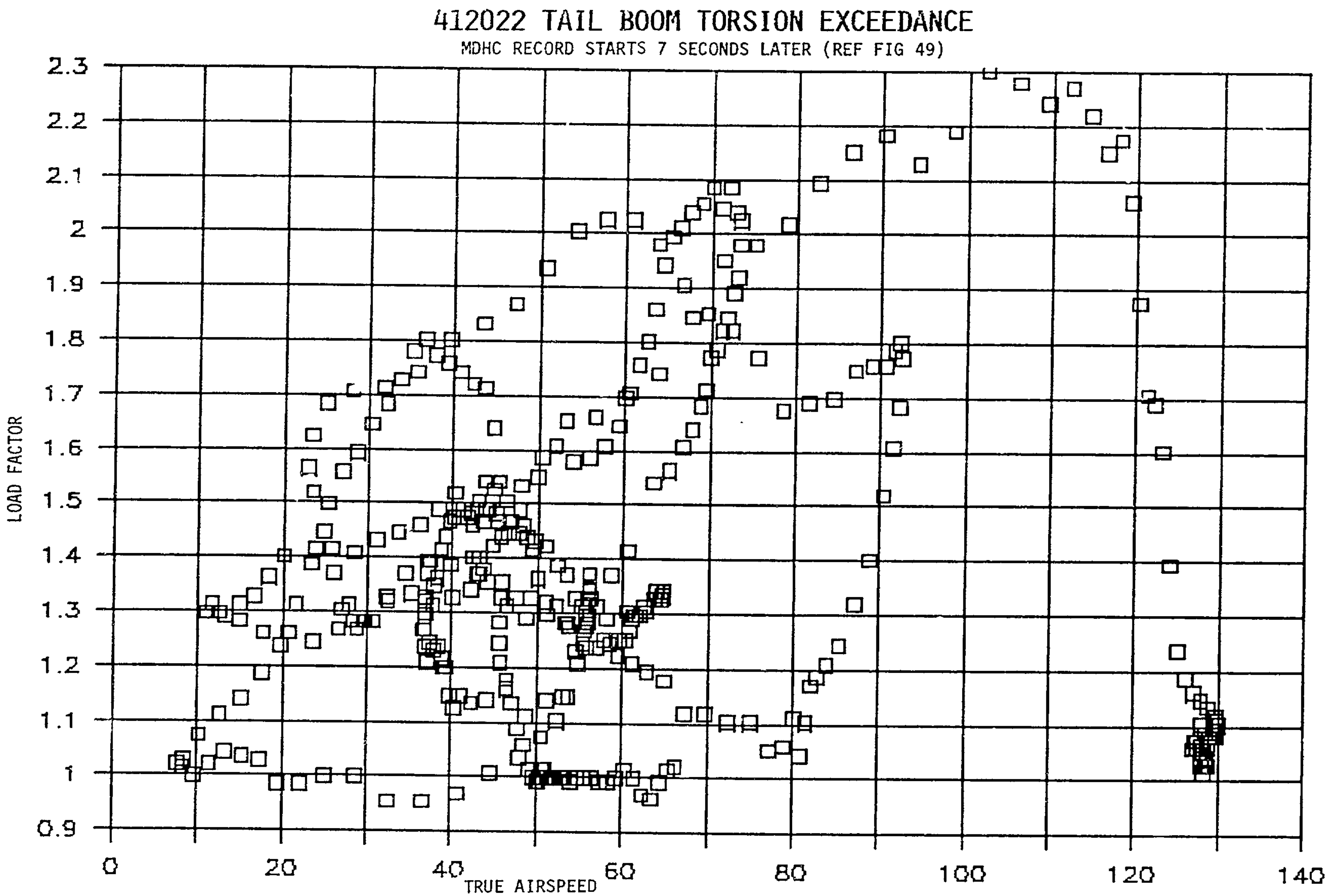


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Continued)

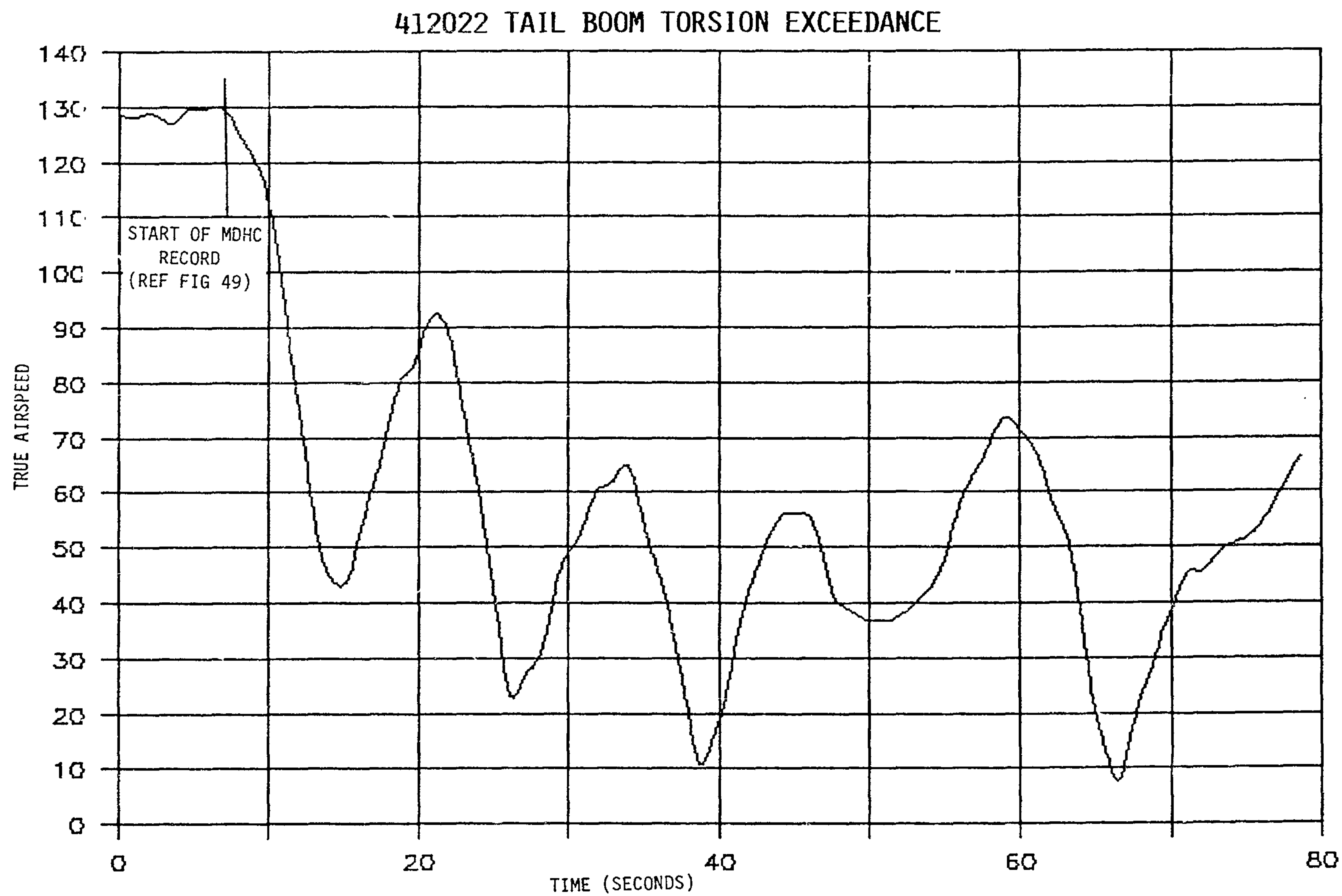


Figure 55. AH-64A state parameter time histories during fuselage tail boom skin fatigue damage. (Concluded)

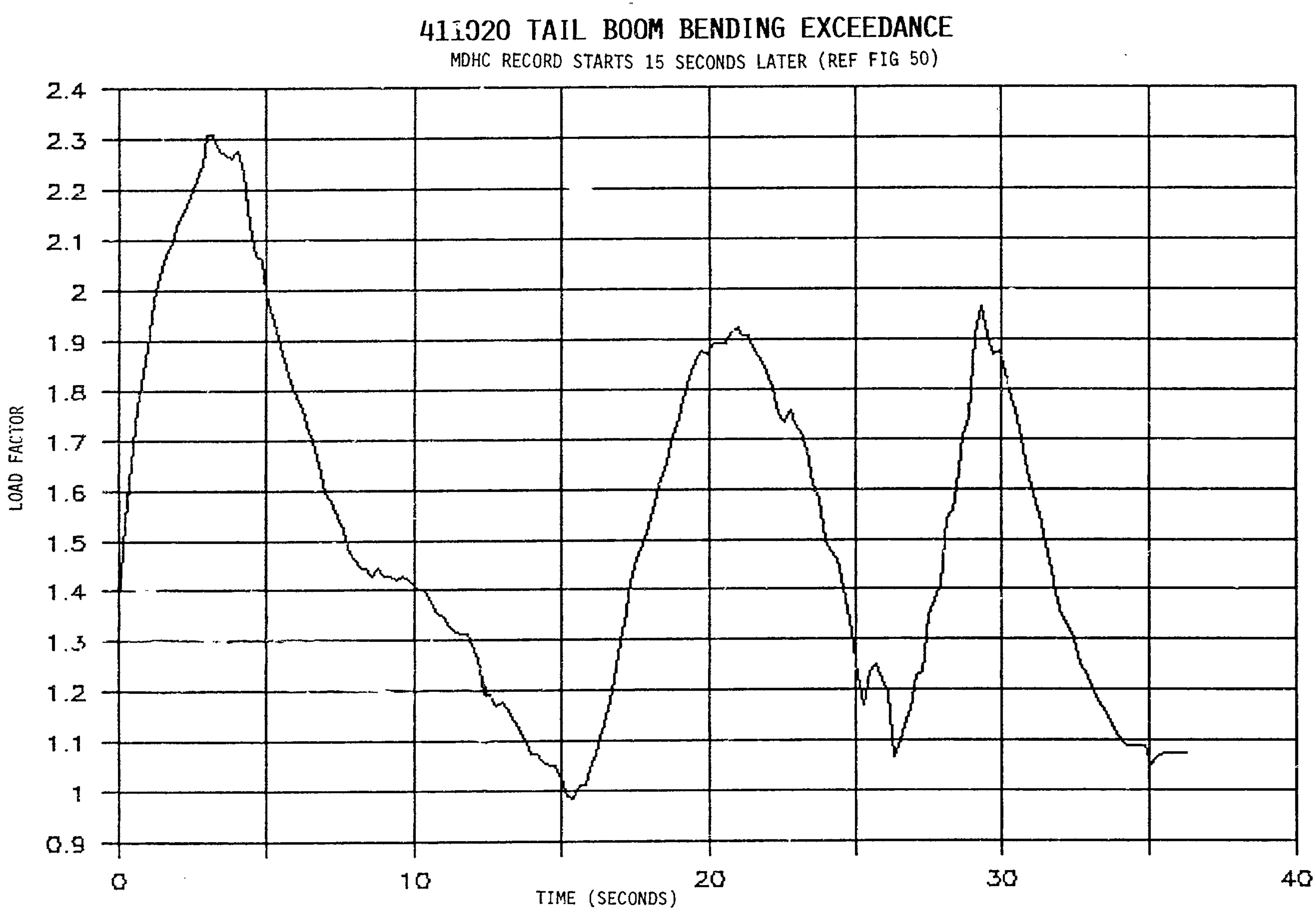


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage.

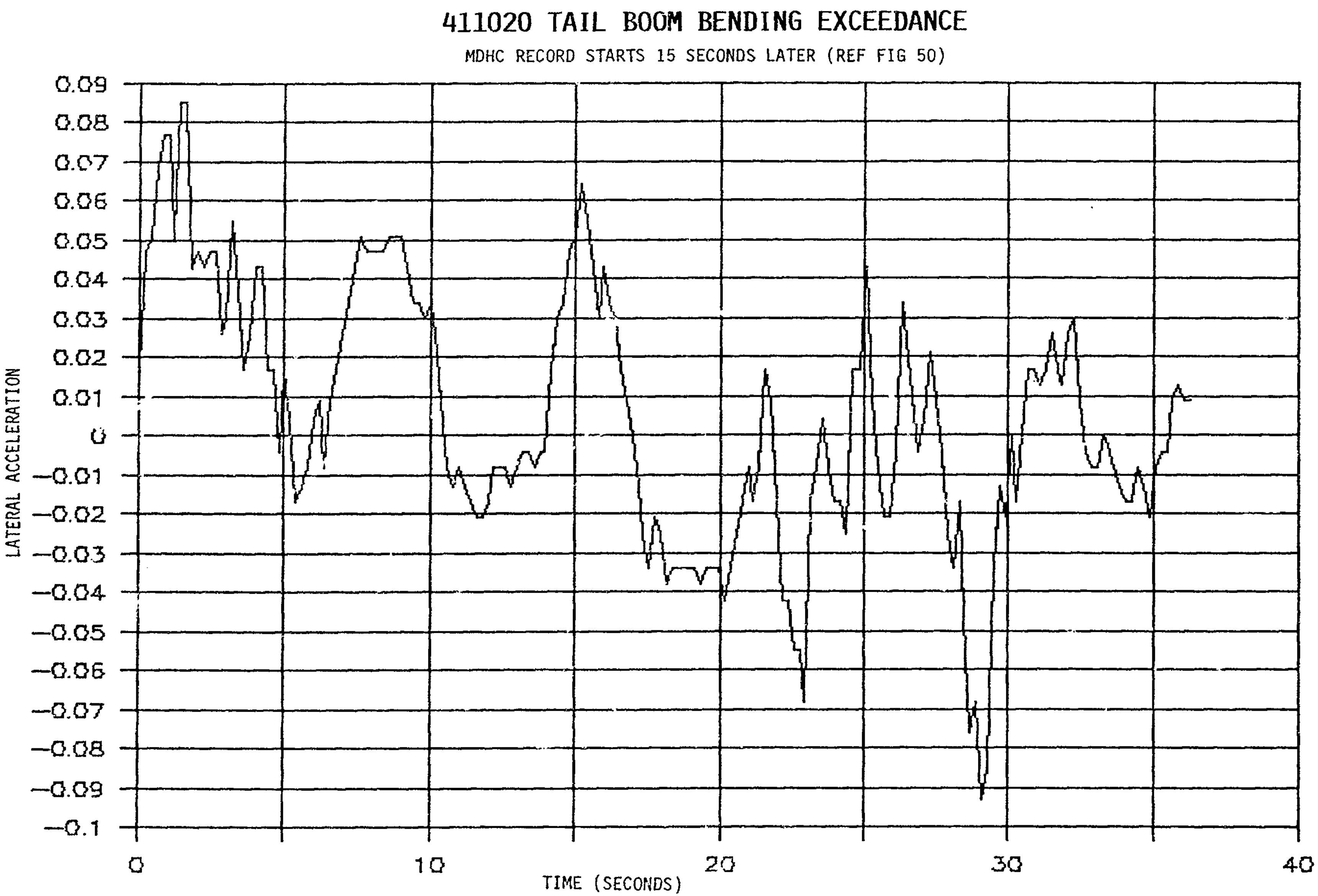
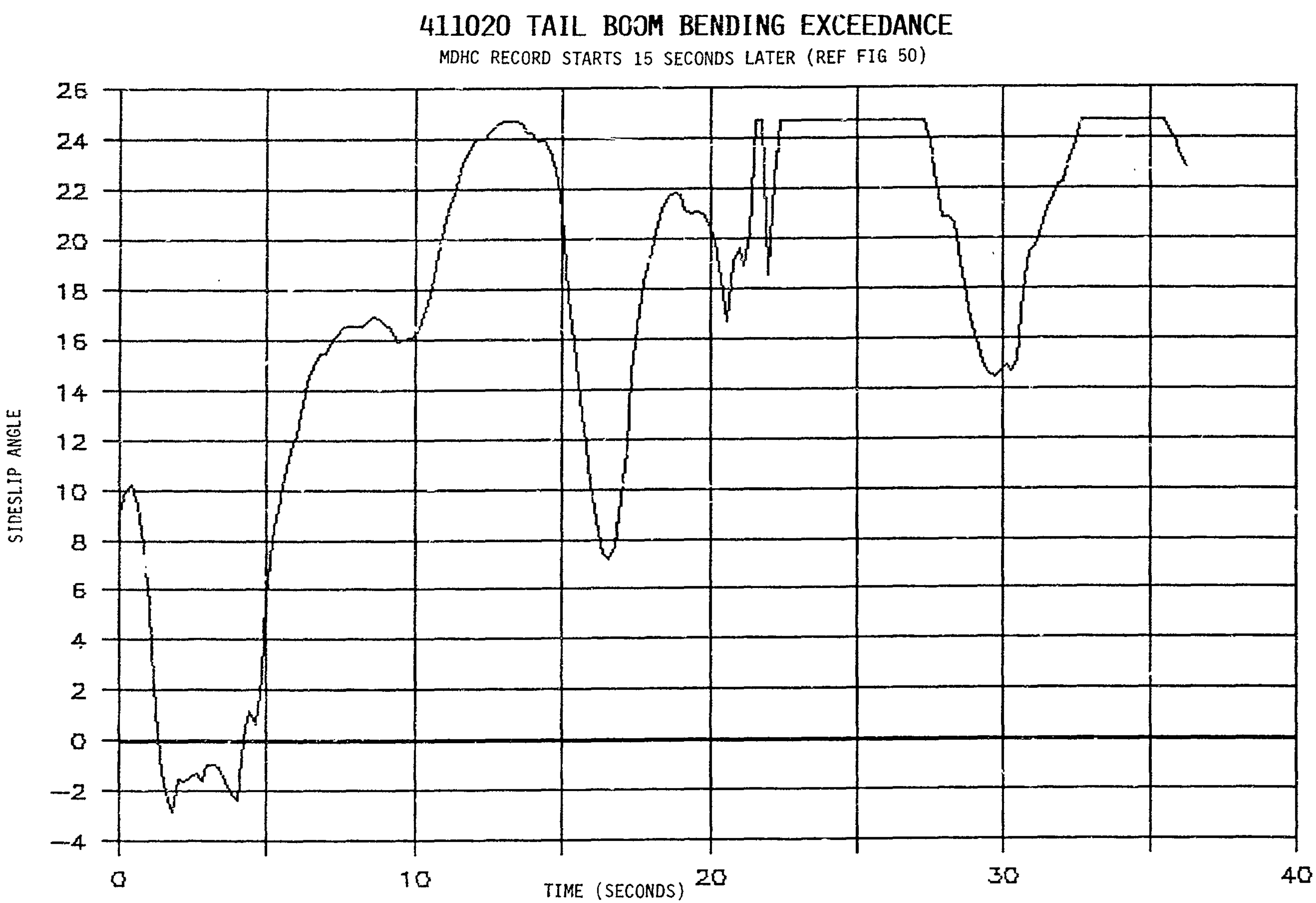


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage. (Continued)



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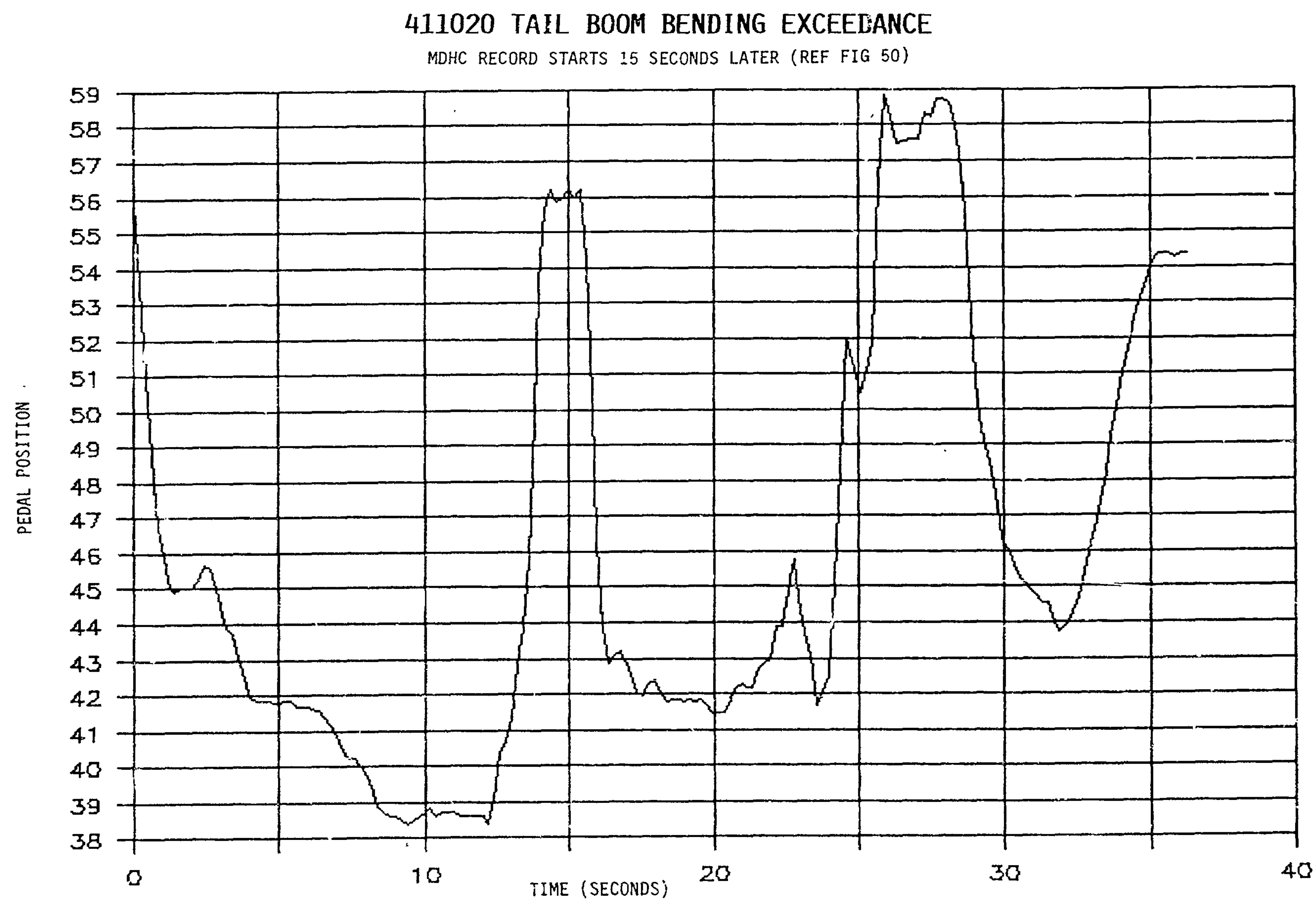

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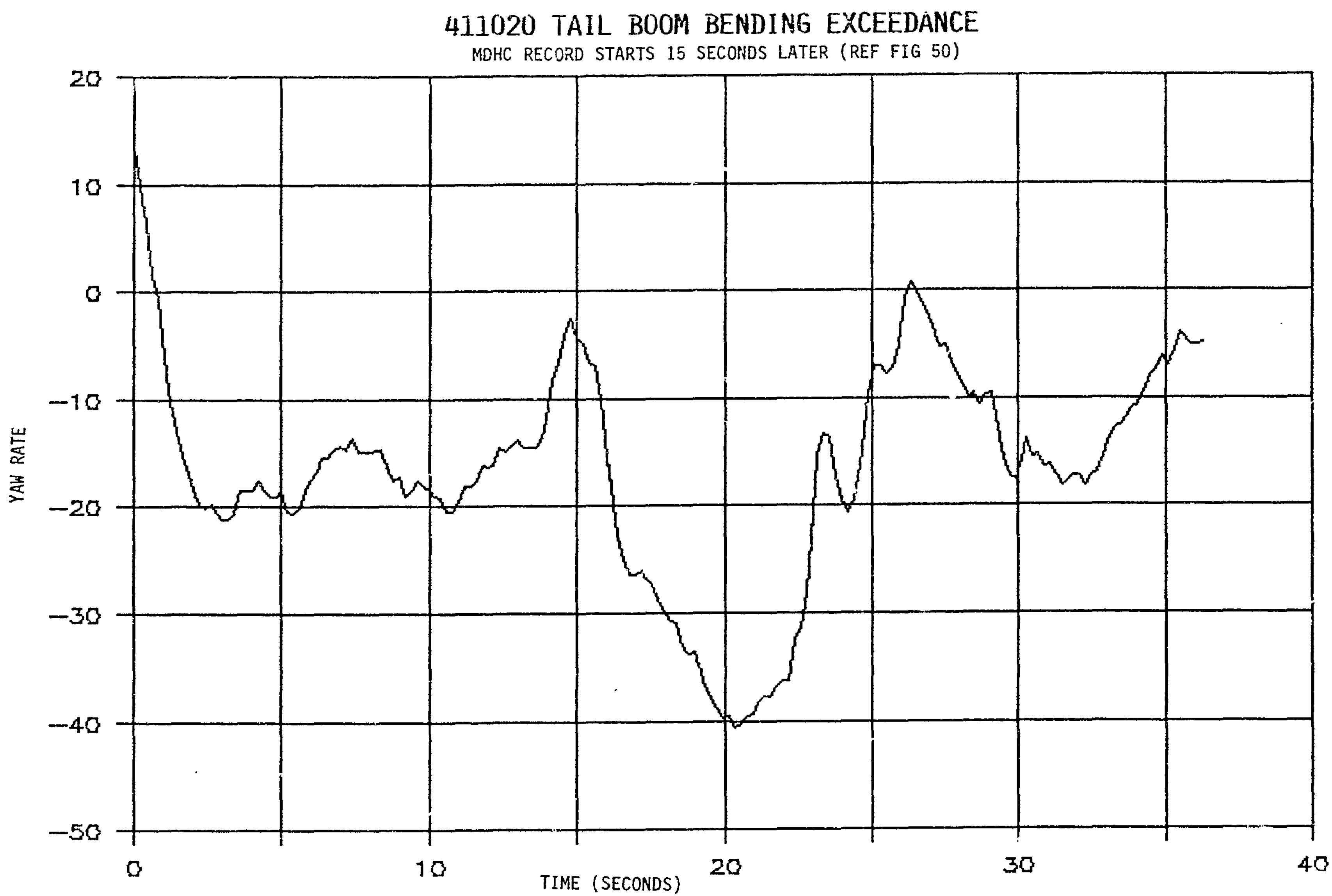

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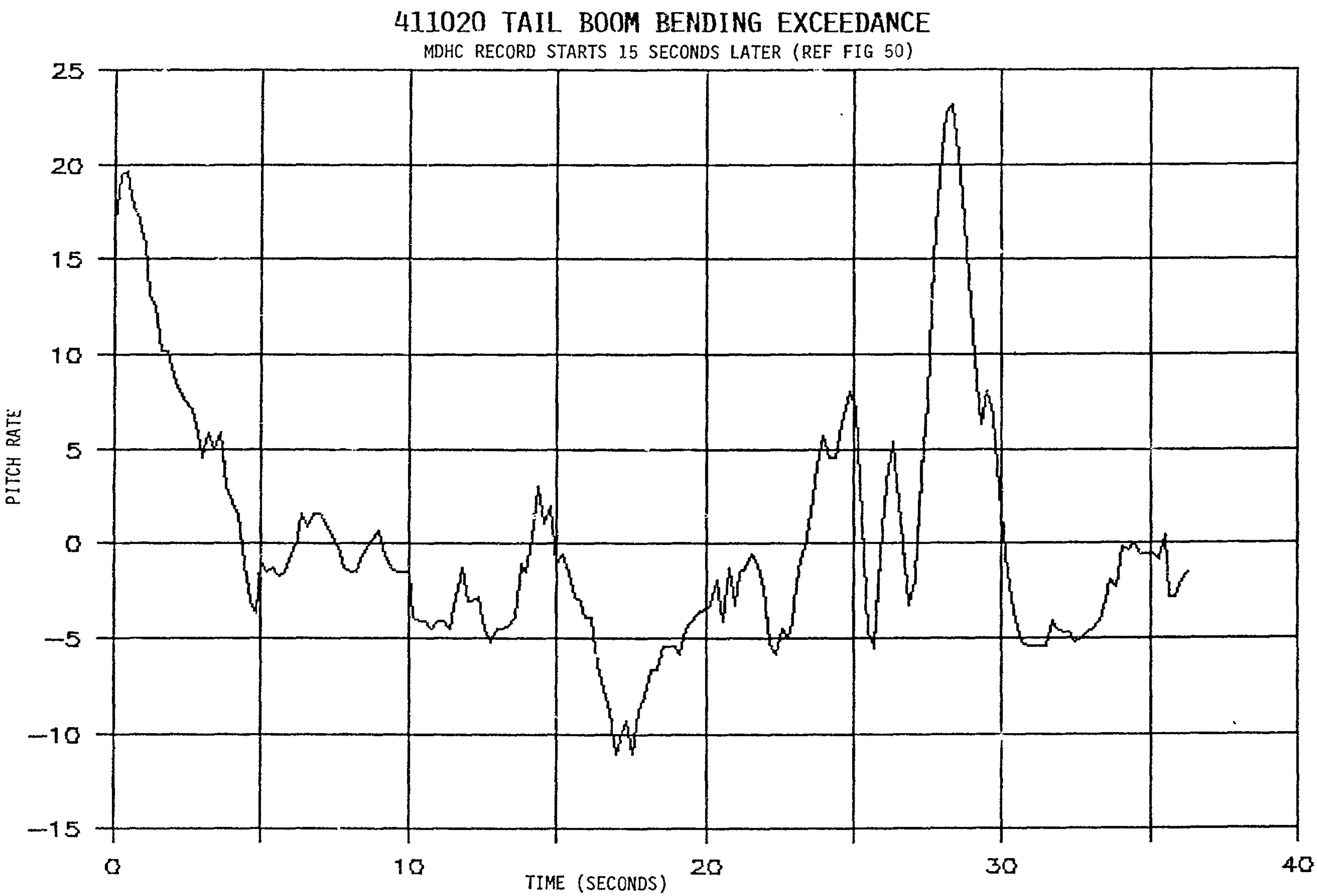
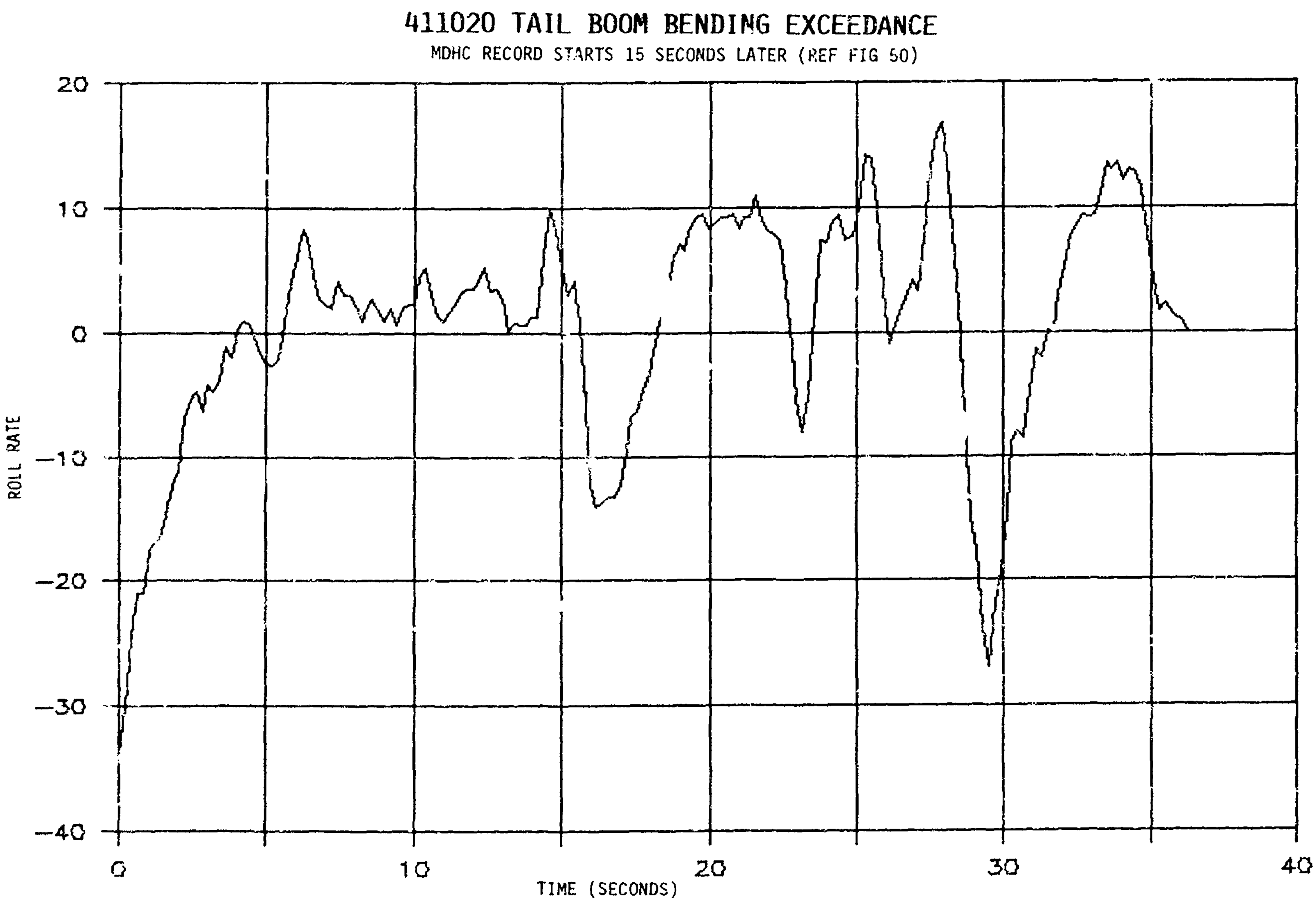


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage. (Continued)



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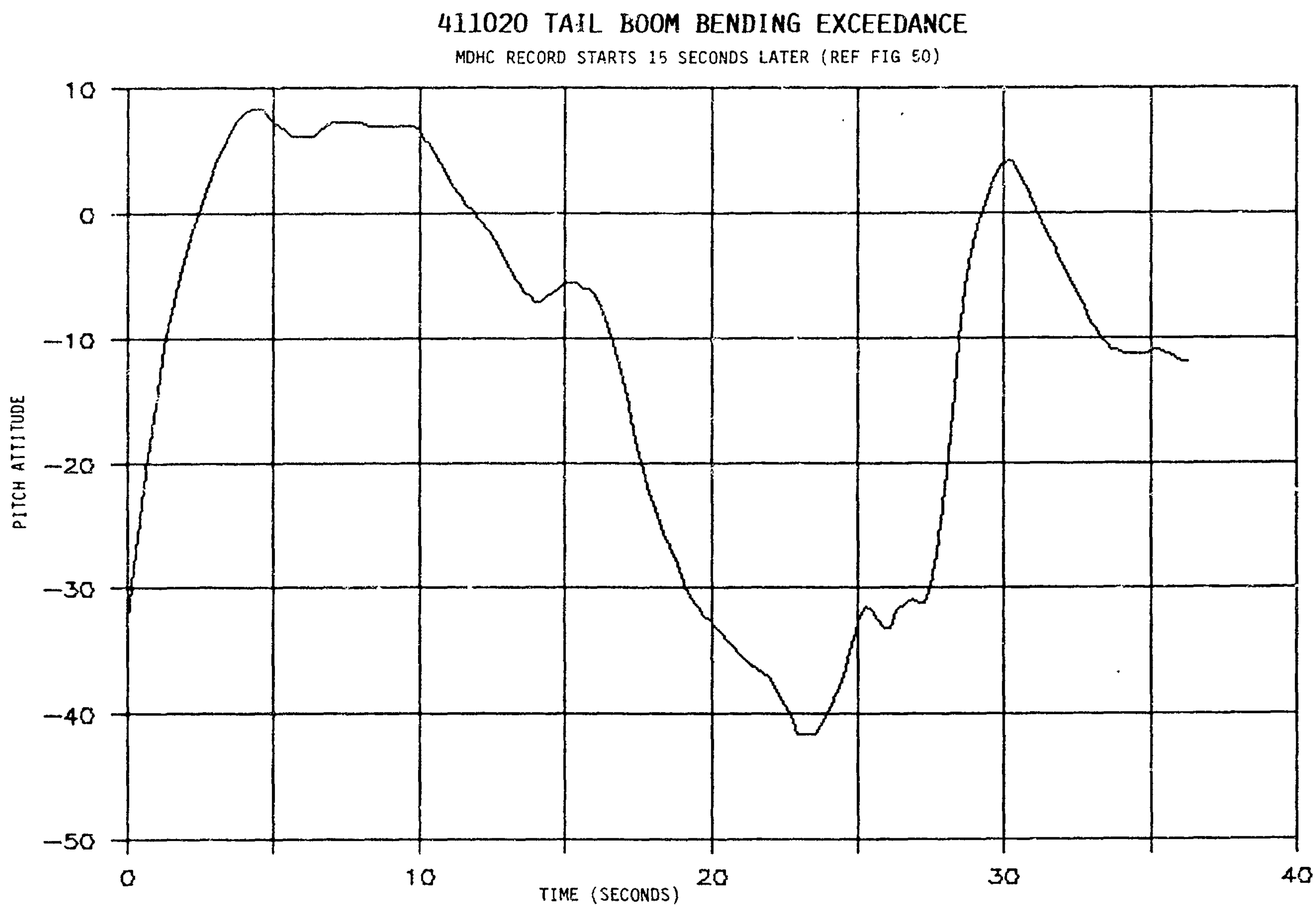
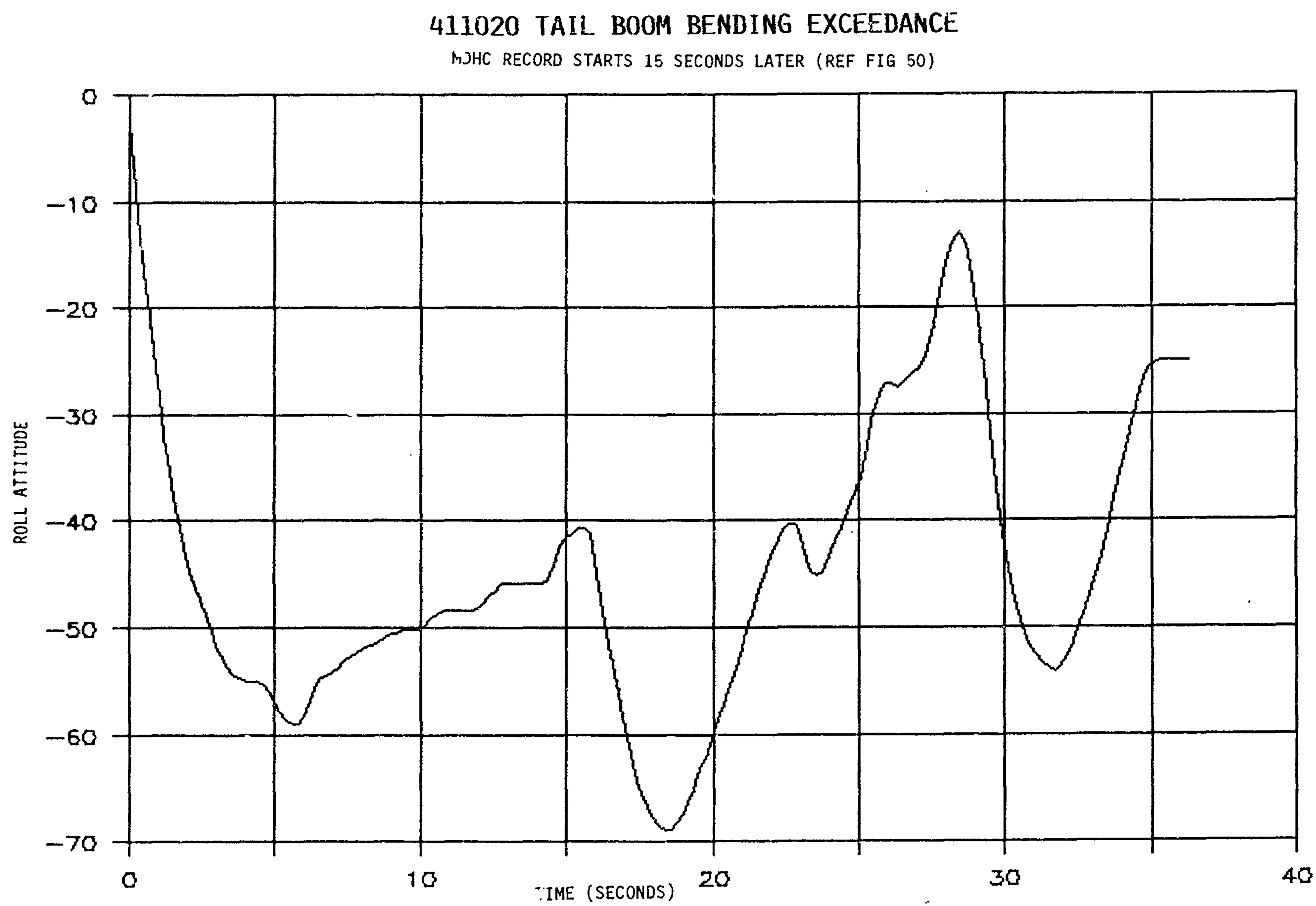


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage. (Continued)



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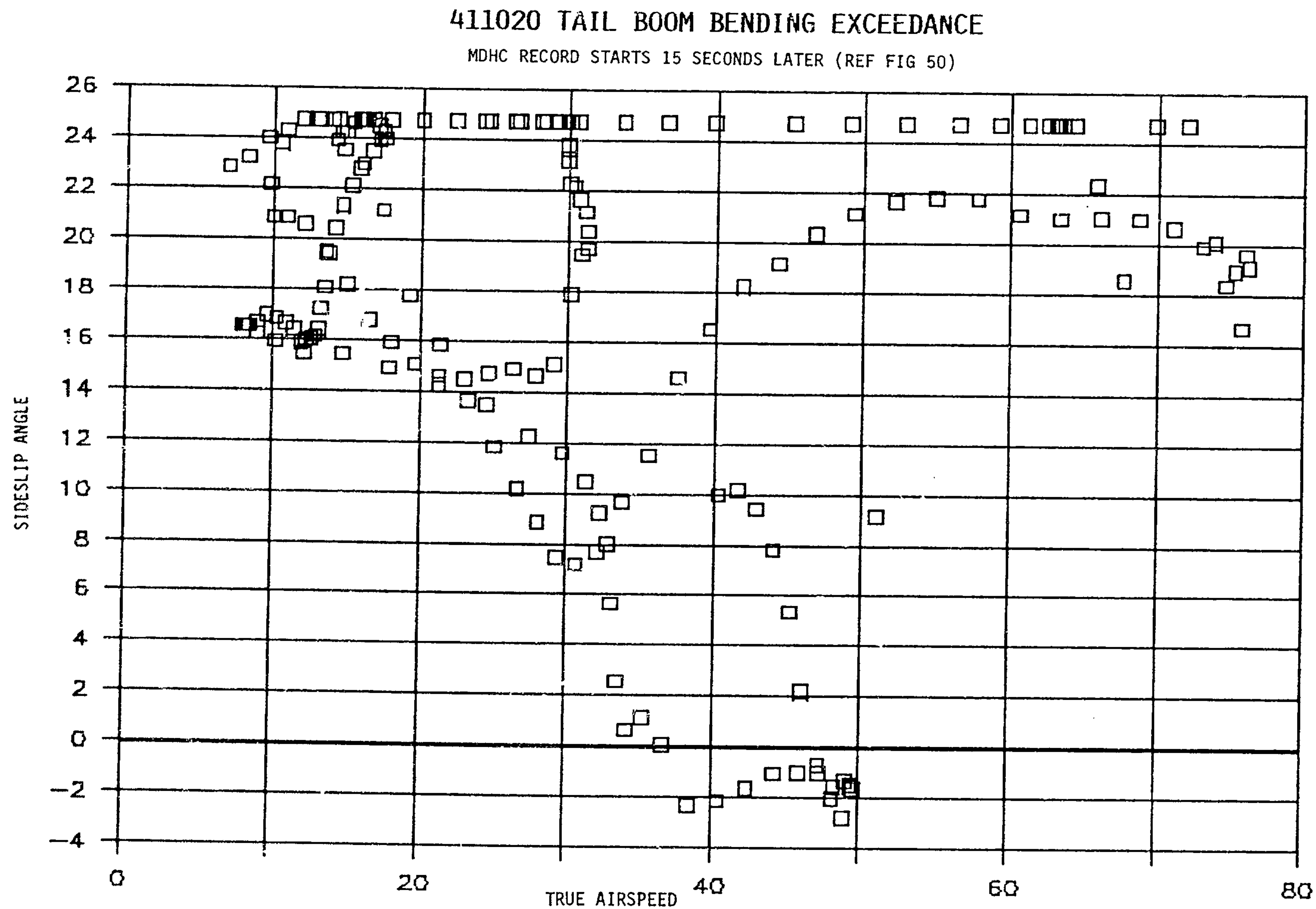


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage. (Continued)

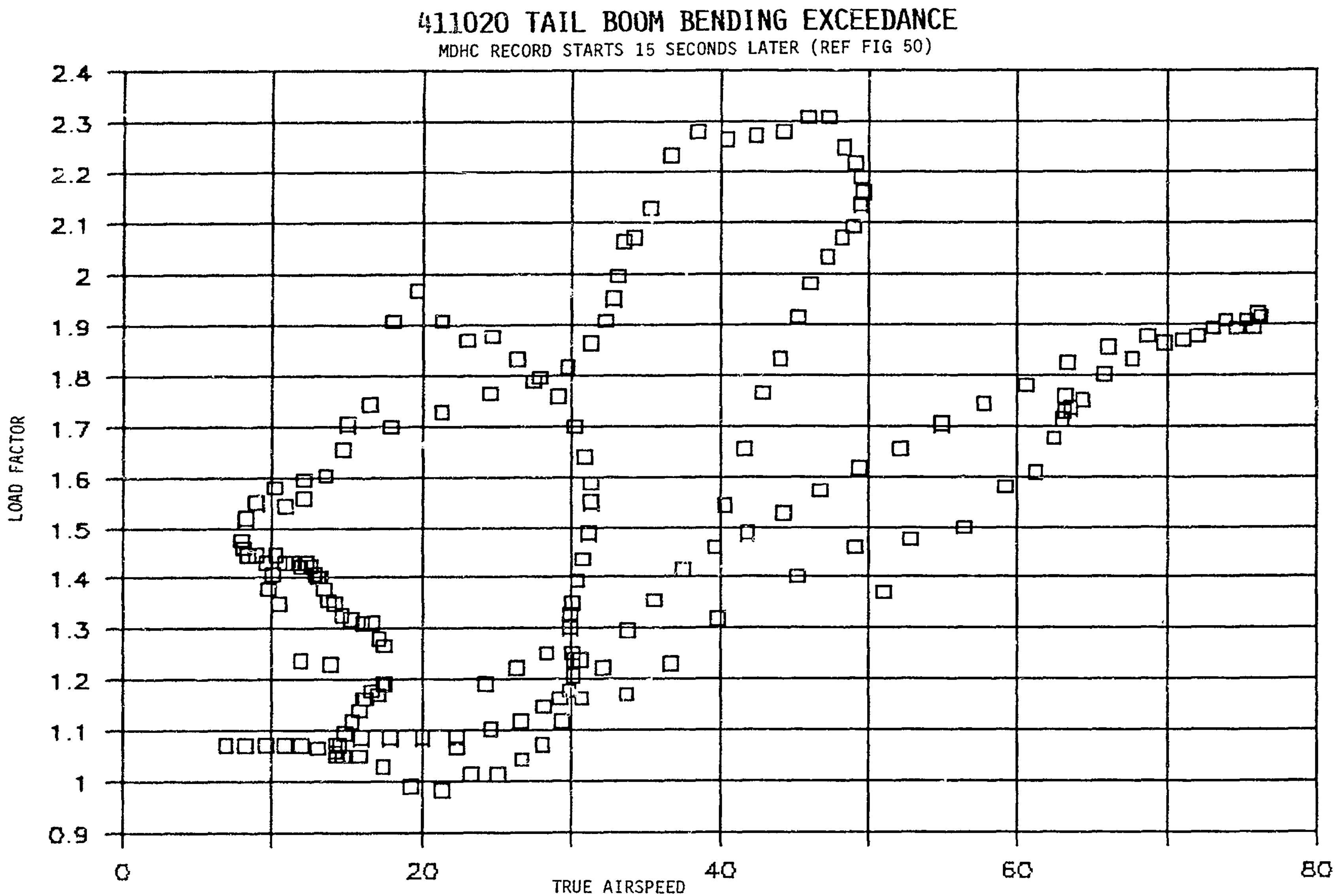


Figure 56. AH-64A state parameter time histories during fuselage tail boom stringer fatigue damage. (Concluded)

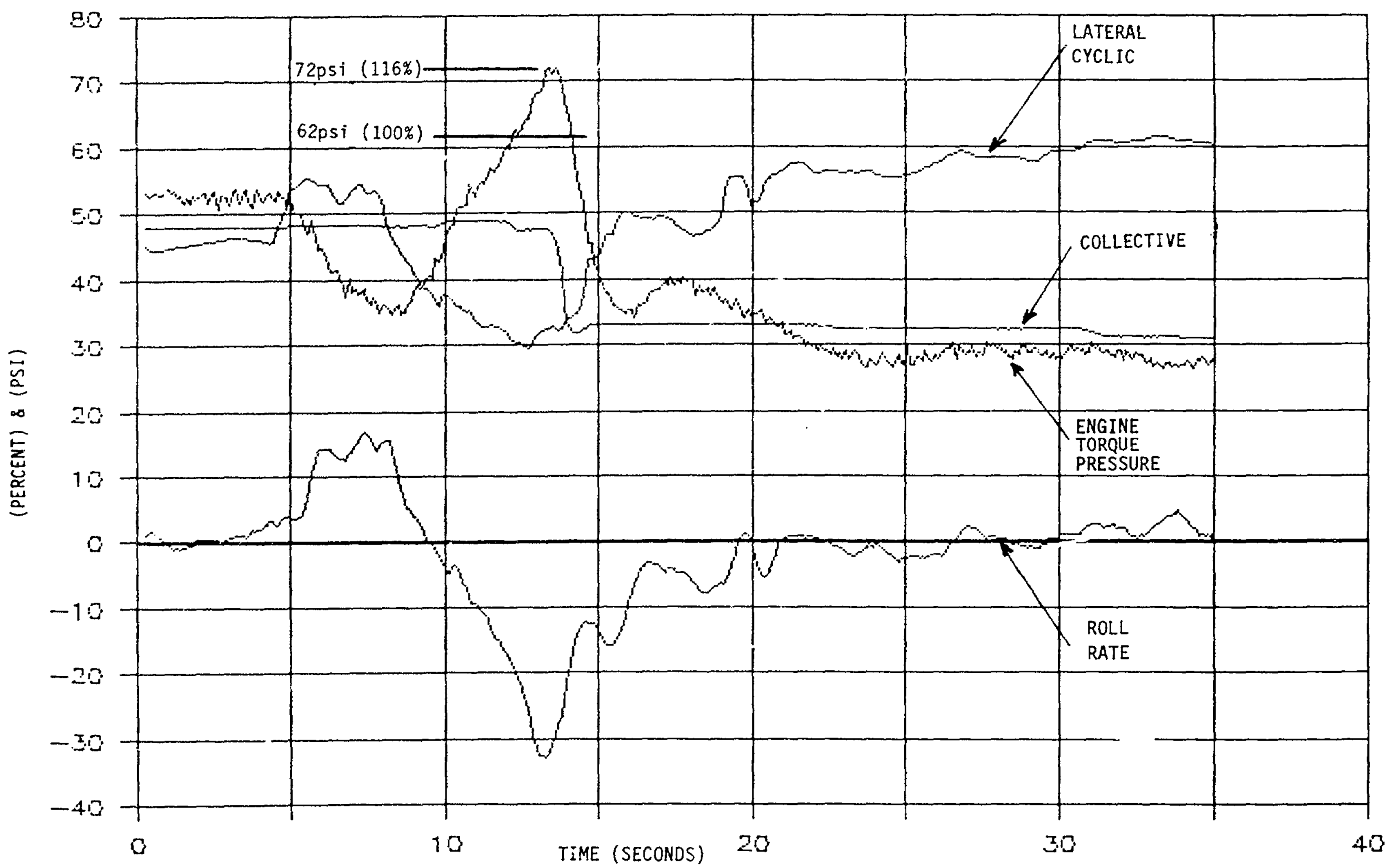


Figure 57. AH-1S overtorque time history (engagement 419009).

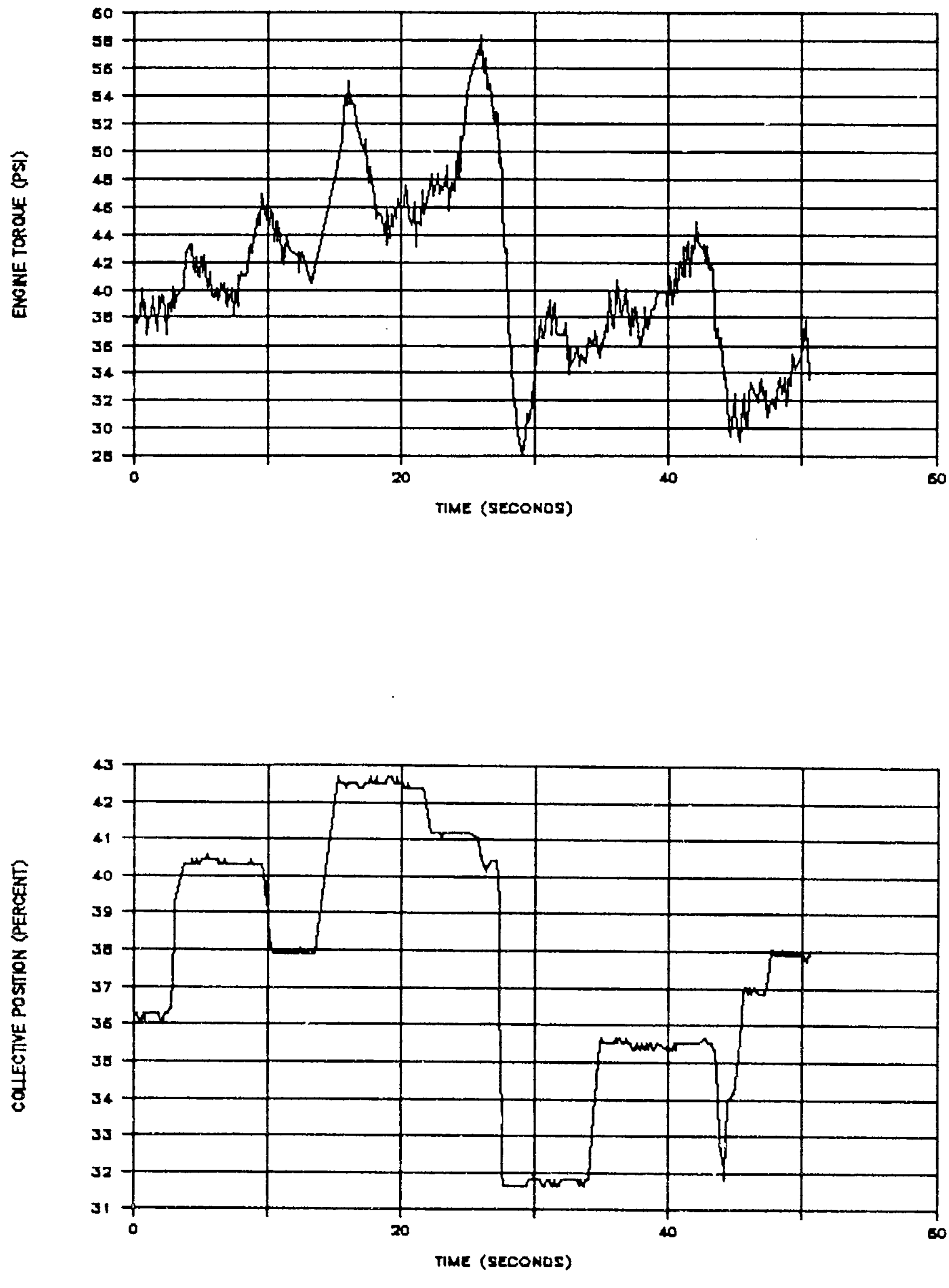
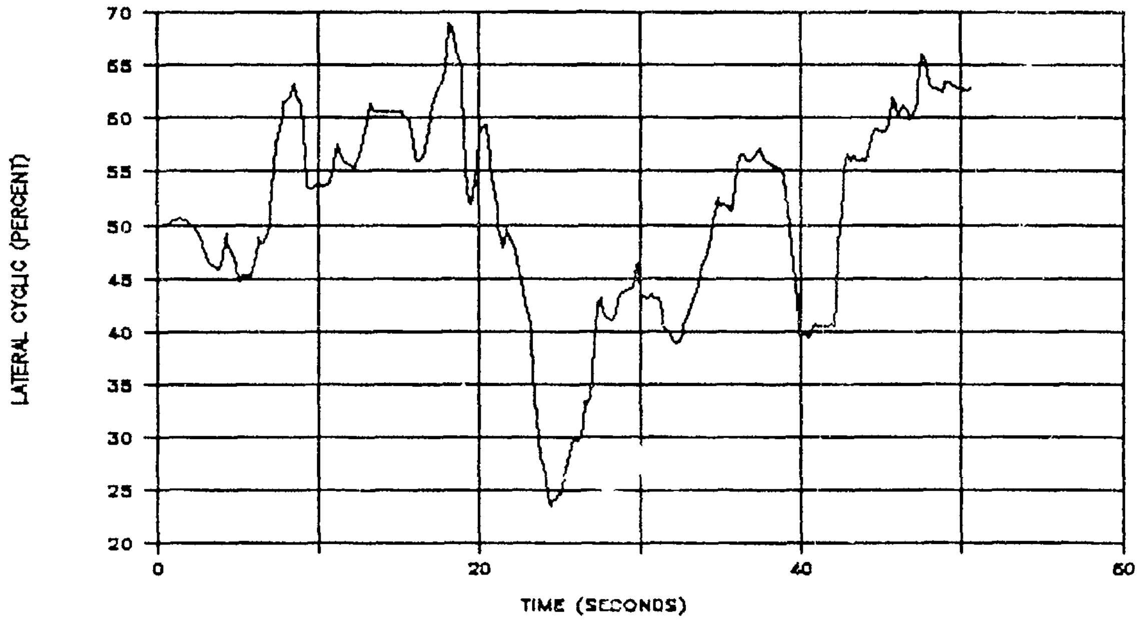


Figure 58. AH-1S flight controls activity (workload) during incipient overtorque condition (engagement 412008).



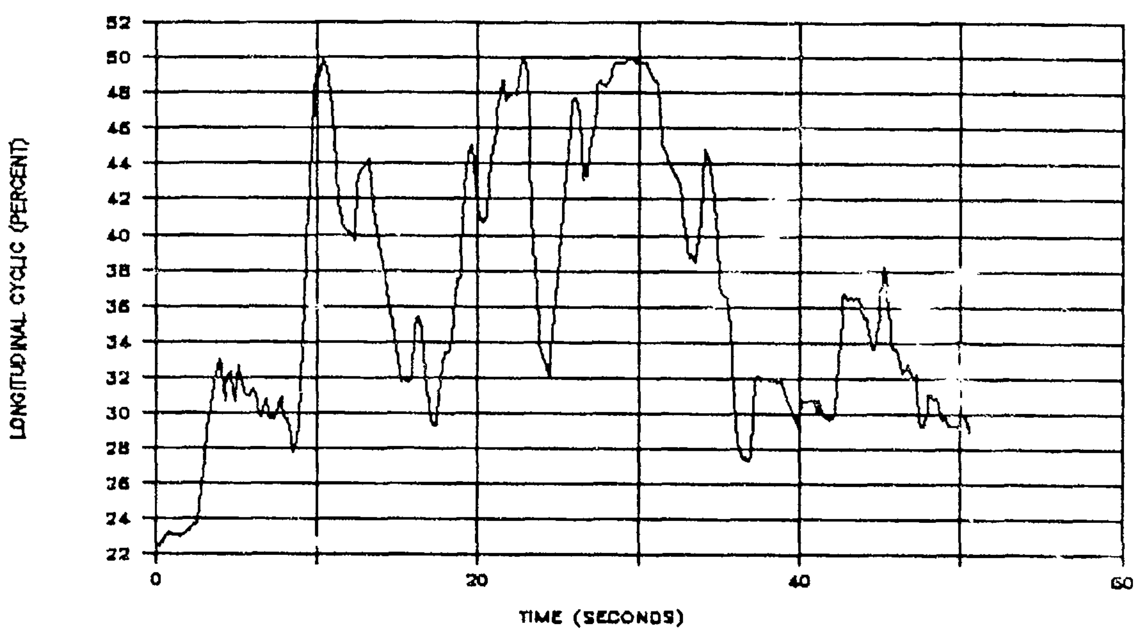


Figure 58. AH-1S flight controls activity (workload) during incipient overtorque condition (engagement 412008). (Concluded)

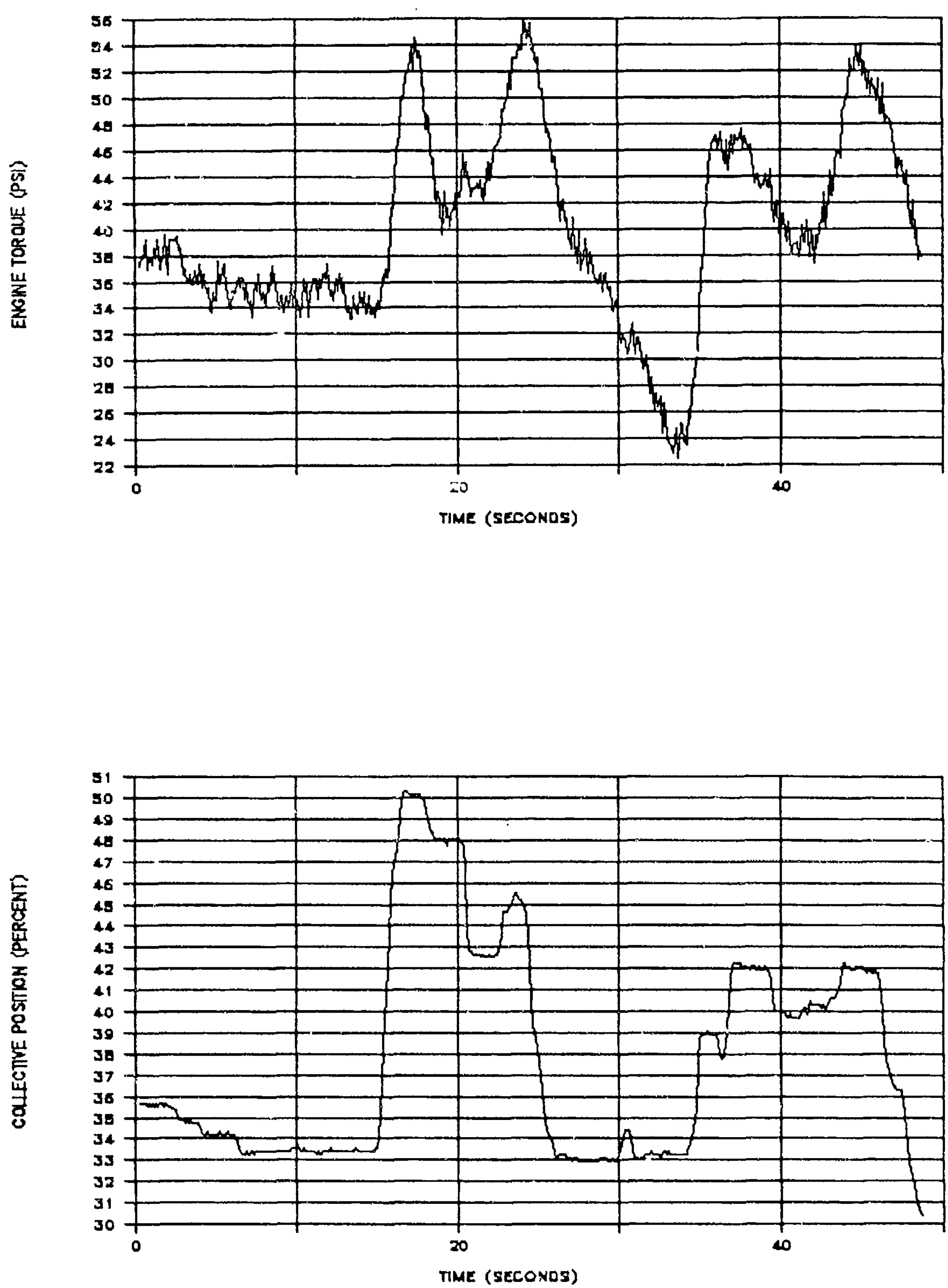
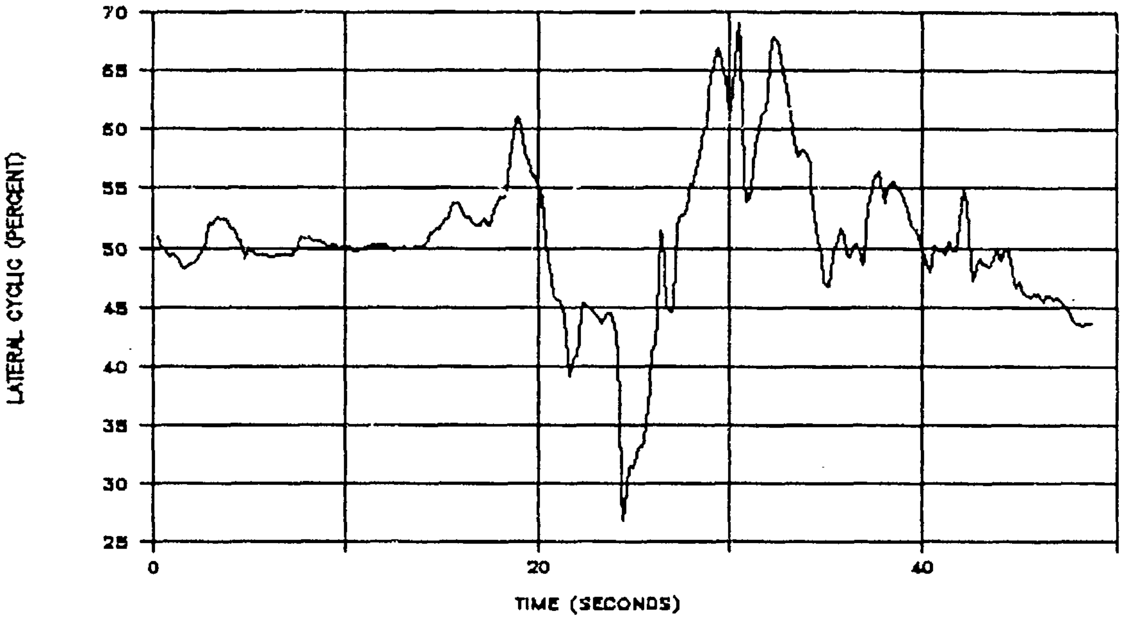


Figure 59. AH-1S flight controls activity (workload) during incipient overtorque condition (engagement 412010).



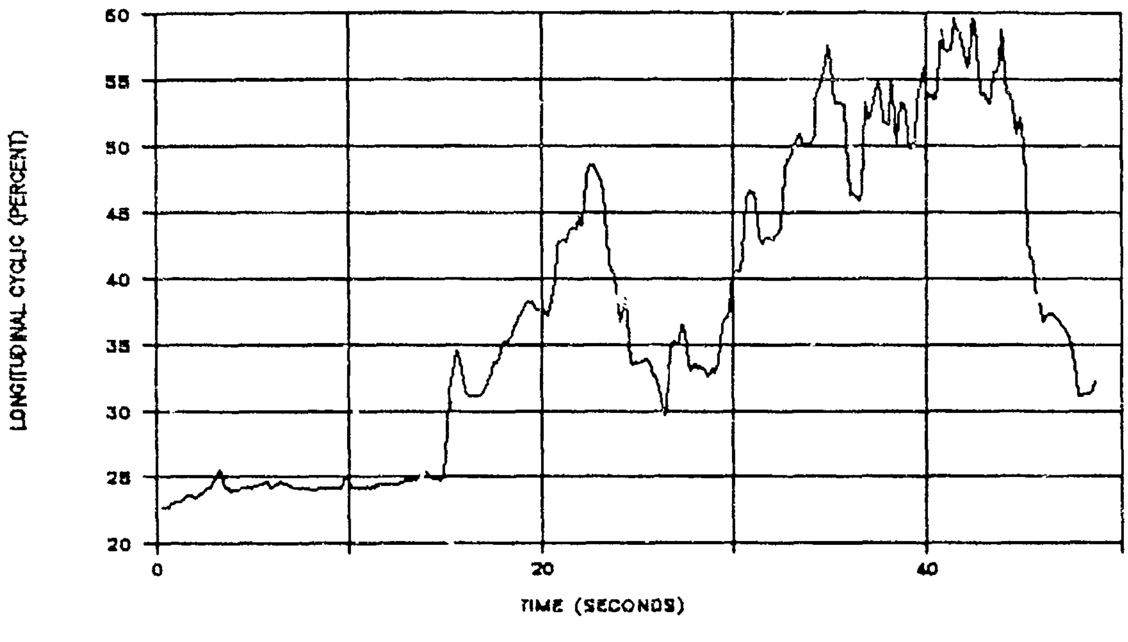


Figure 59. AH-1S flight controls activity (workload) during incipient overtorque condition (engagement 412010). (Concluded)

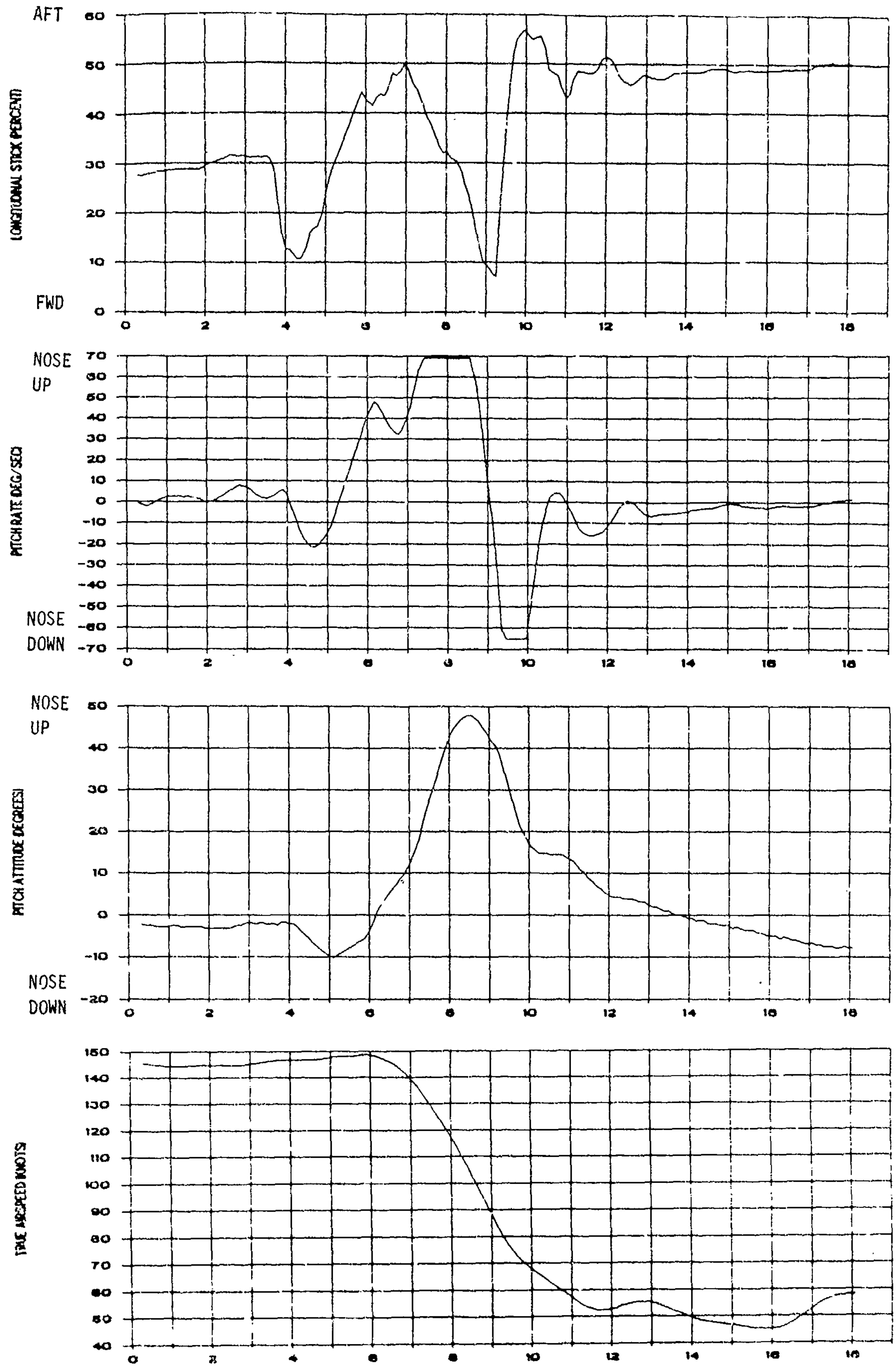


Figure 60. SA-365N-1 "jack stall" time history.

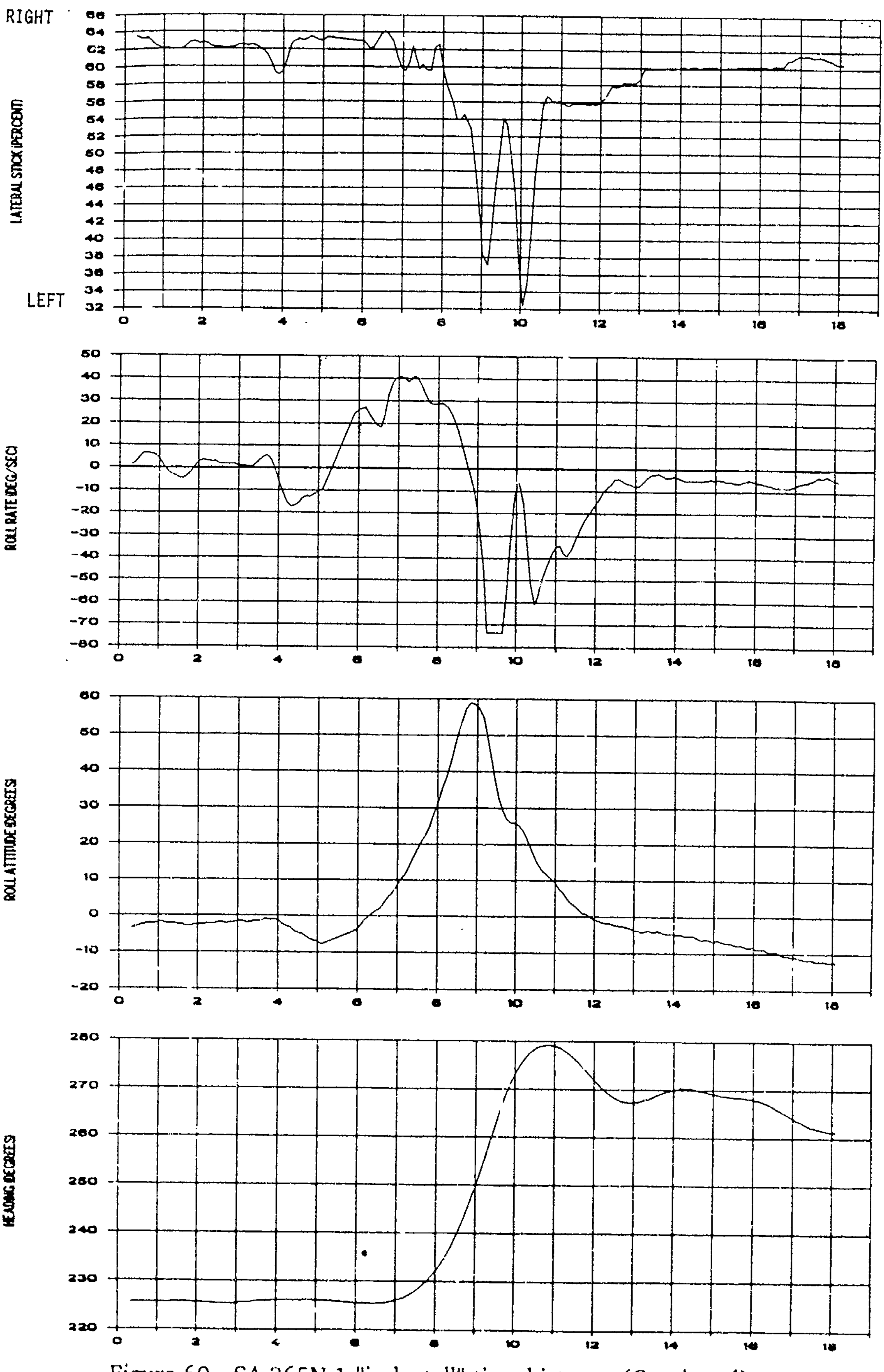


Figure 60. SA-365N-1 "jack stall" time history. (Continued)

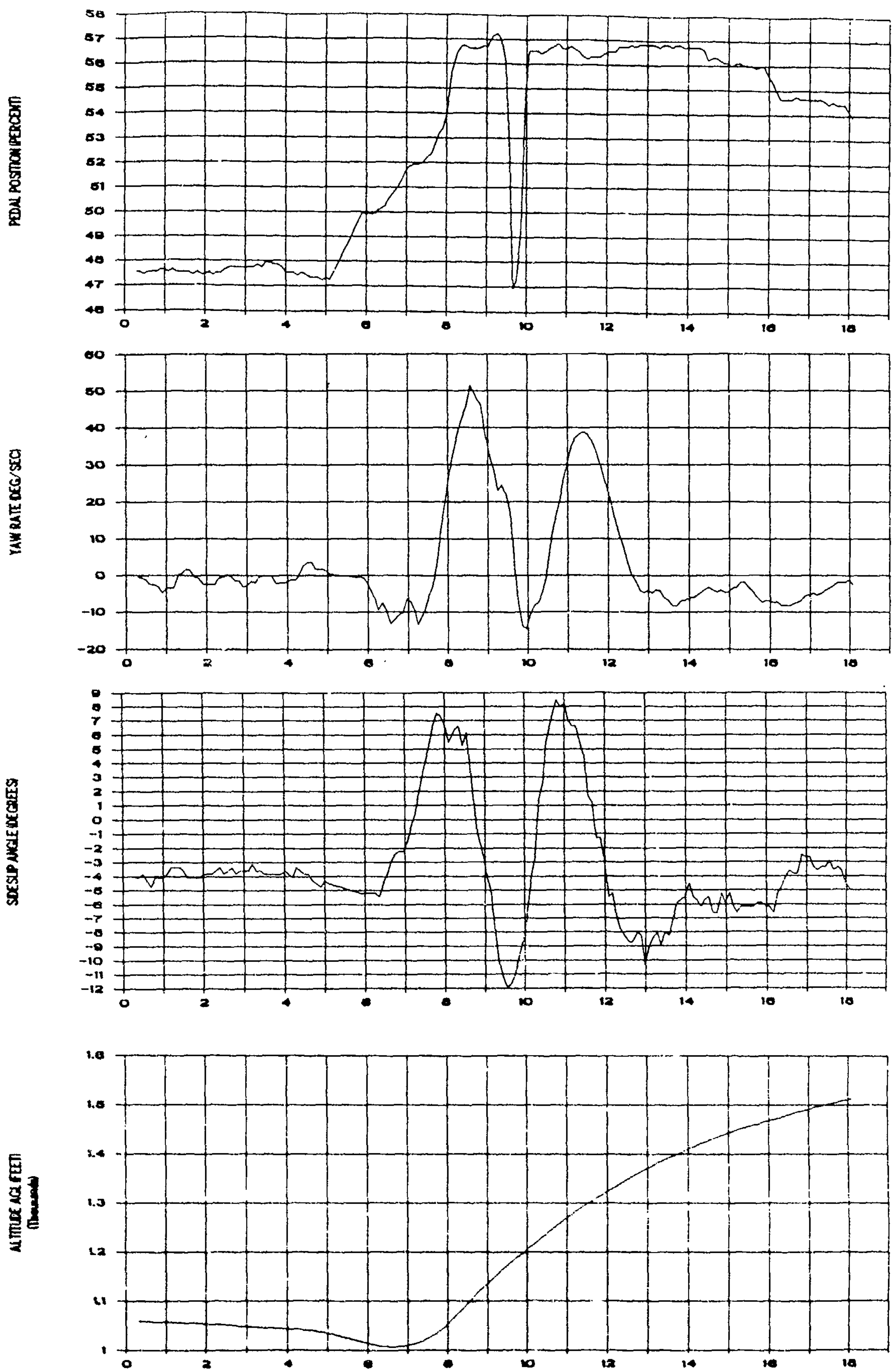


Figure 60. SA-365N-1 "jack stall" time history. (Continued)

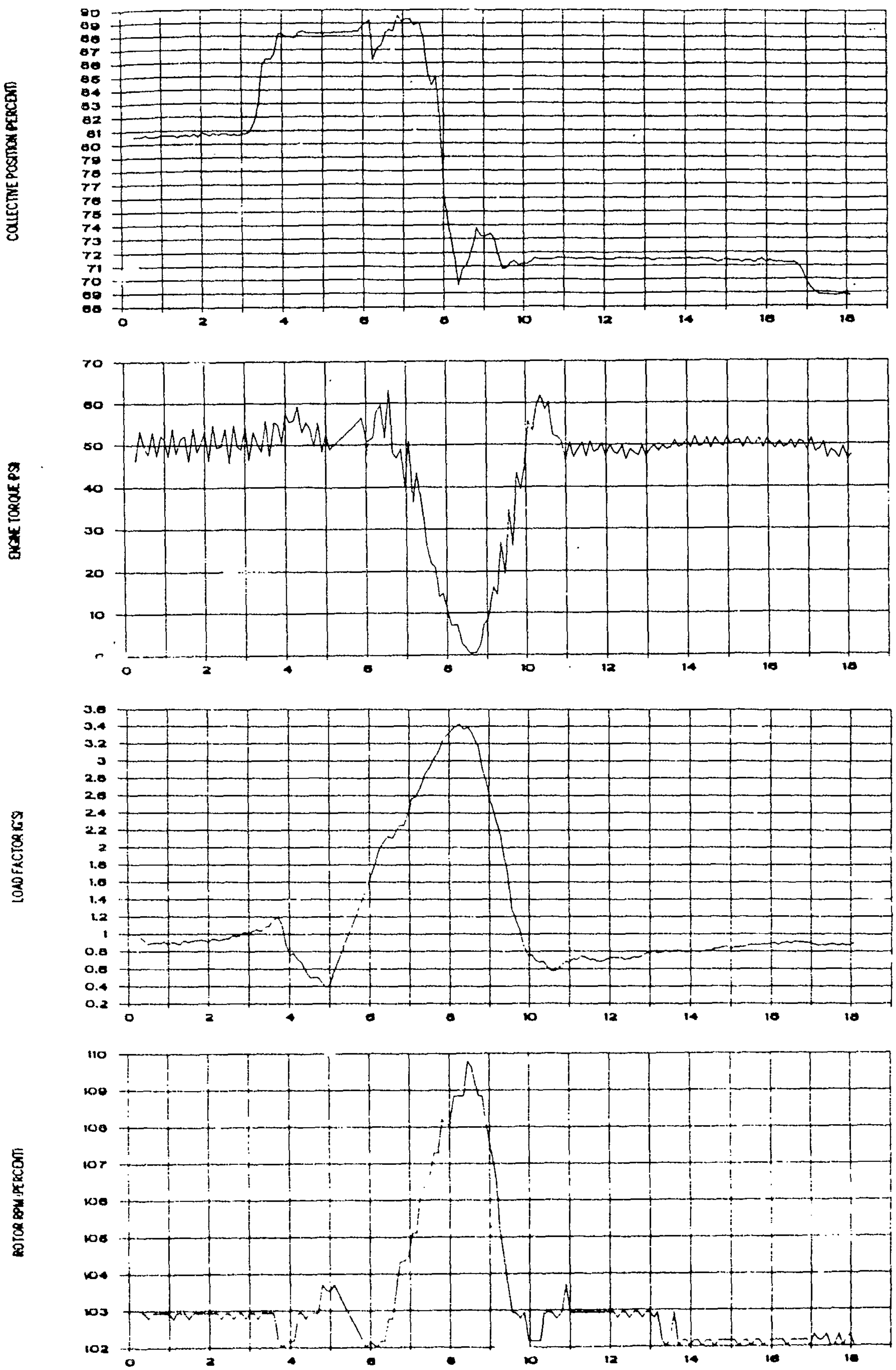


Figure 60. SA-365N-1 "jack stall" time history. (Concluded)

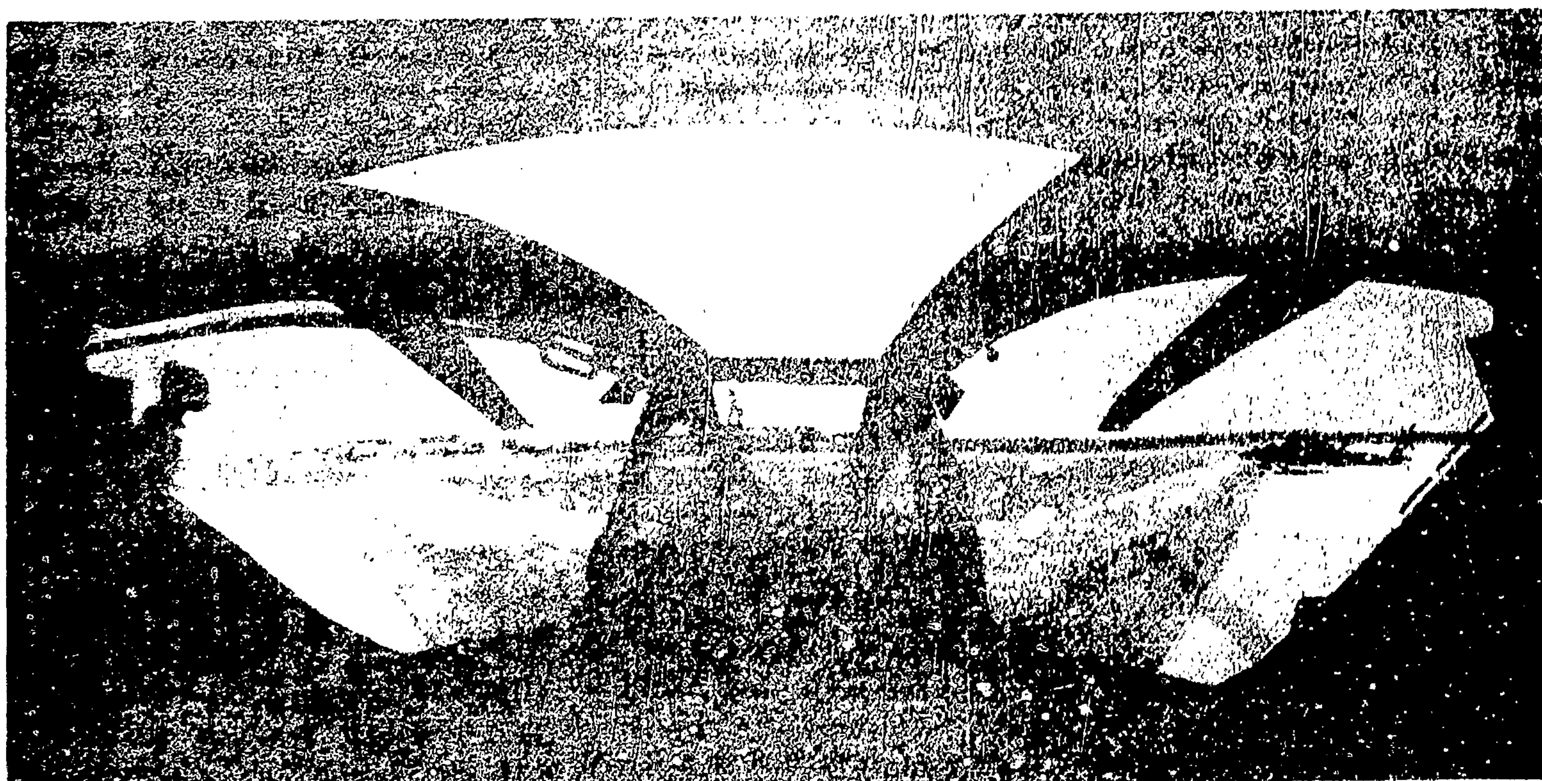


Figure 61. AH-64A cockpit field of view from pilot's station.

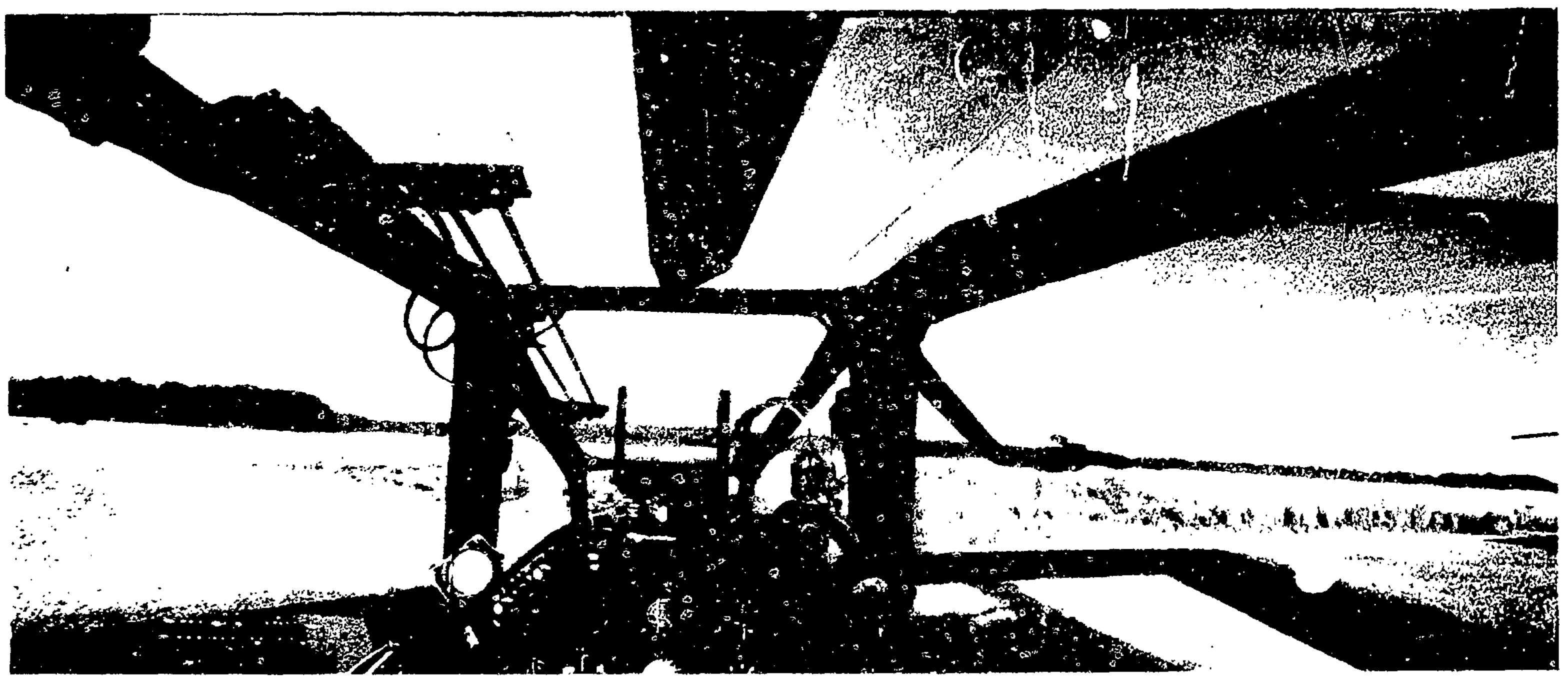


Figure 62. AH-1S cockpit field of view from pilot's station.

Figure 63. OH-58D cockpit field of view from pilot's station.

Figure 64. Aviator helmets - Army SPH-4, Apache IHADSS, and Air Force HGU-55/P.

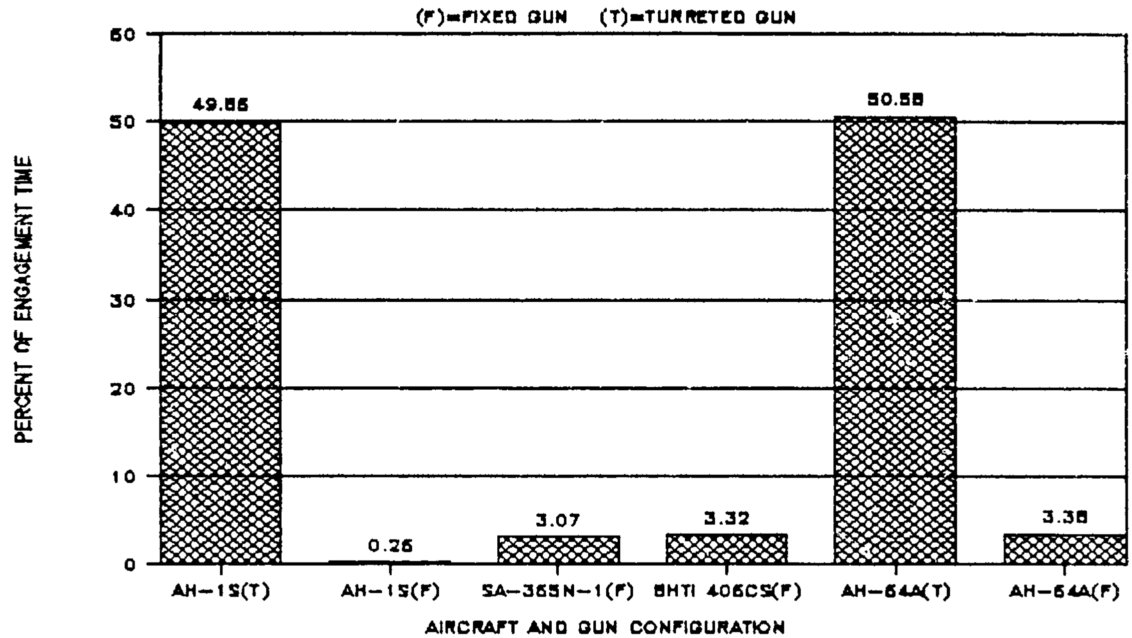


Figure 65. Line-of-sight firing opportunities - fixed and turreted gun modes.

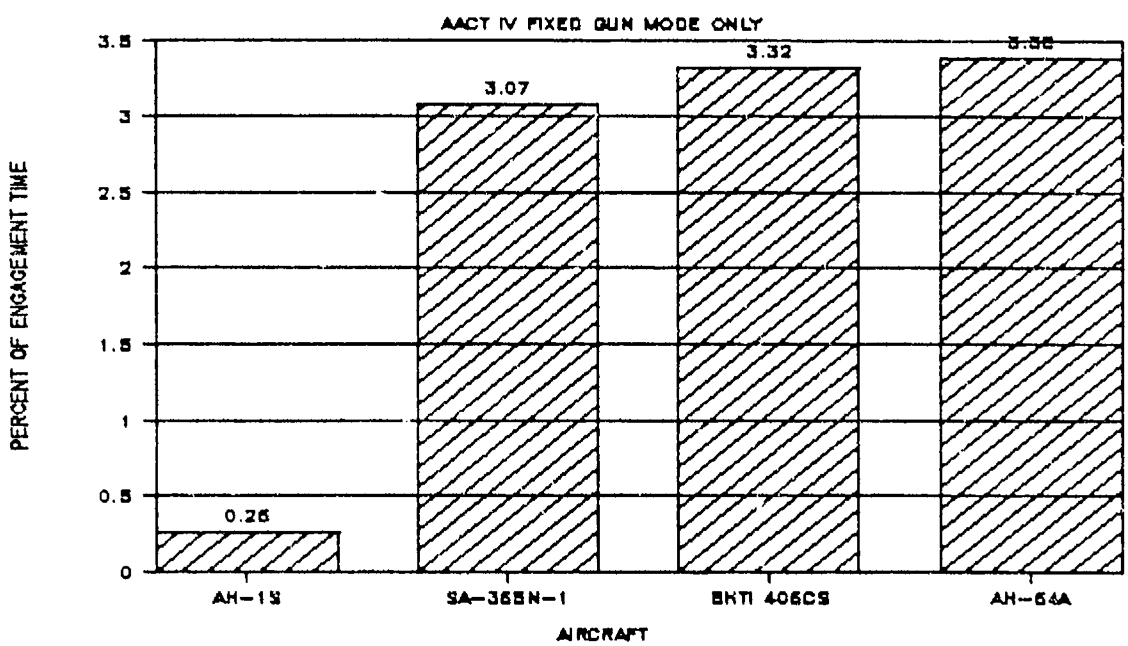
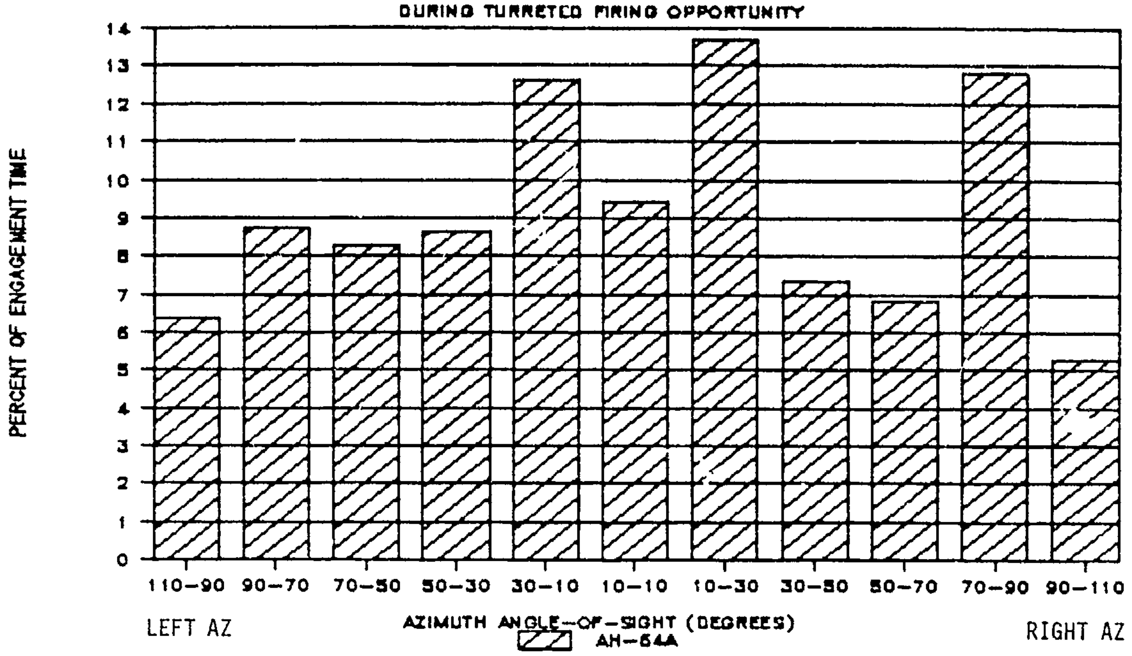


Figure 66. Line-of-sight firing opportunities - fixed gun mode.



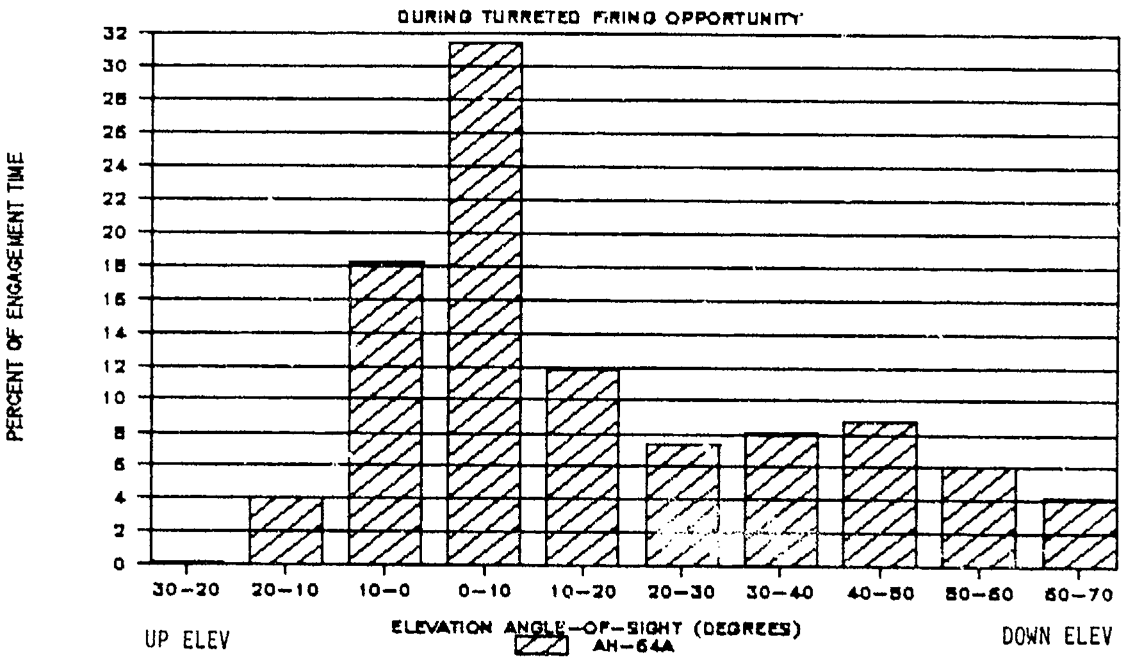
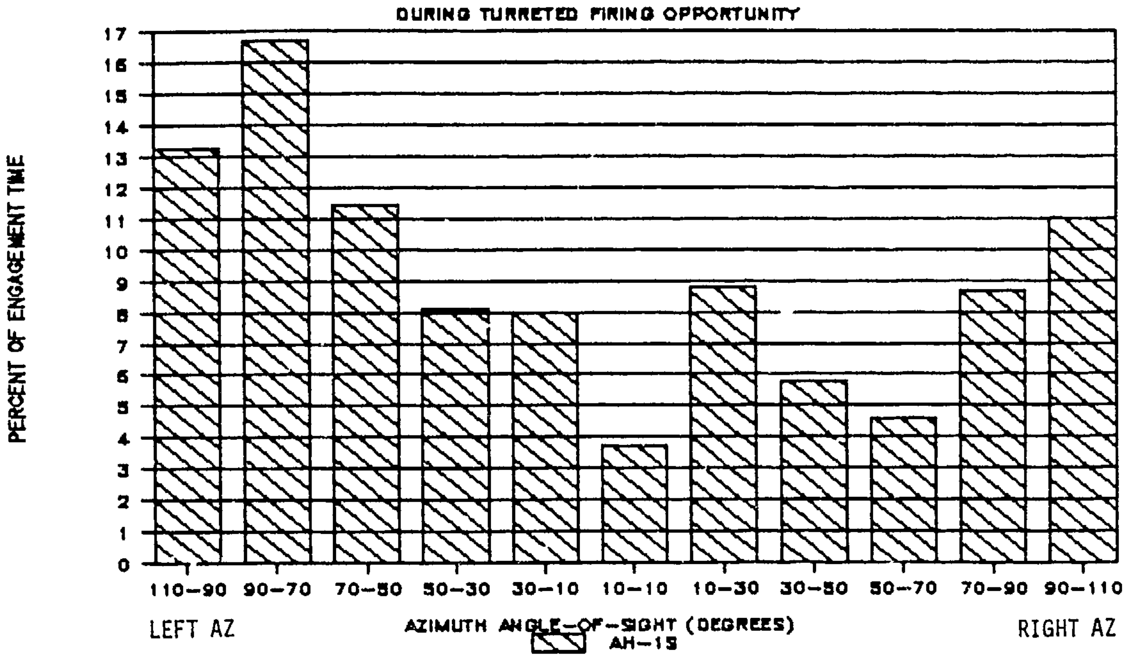


Figure 67. Apache-to-bogey turret window angle-of-sight histograms.



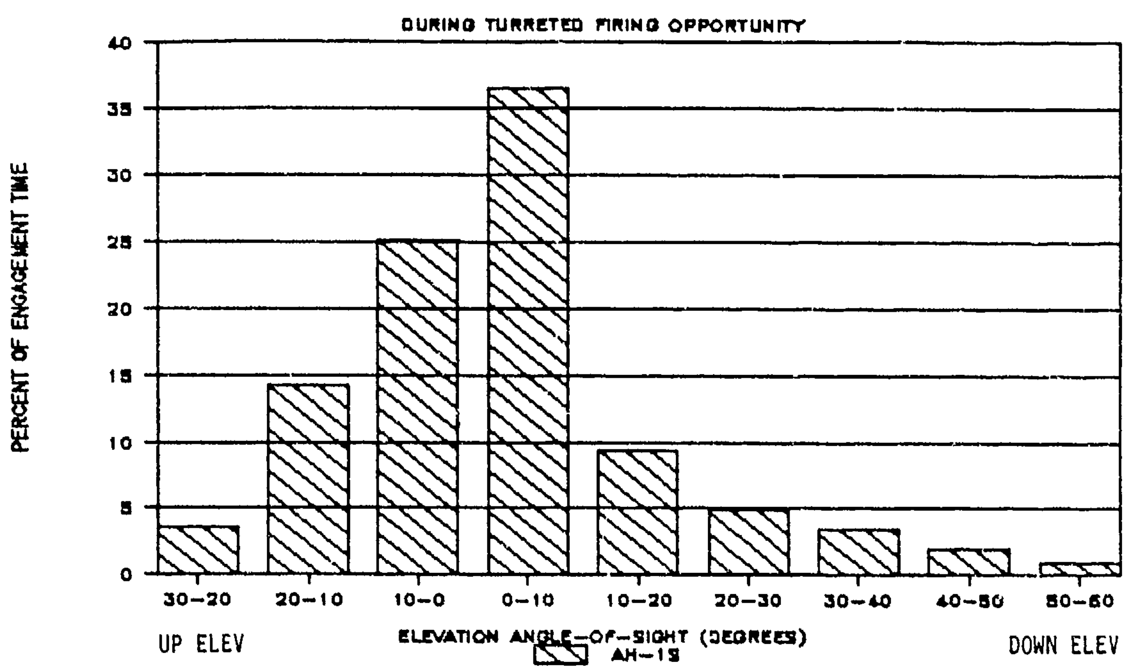
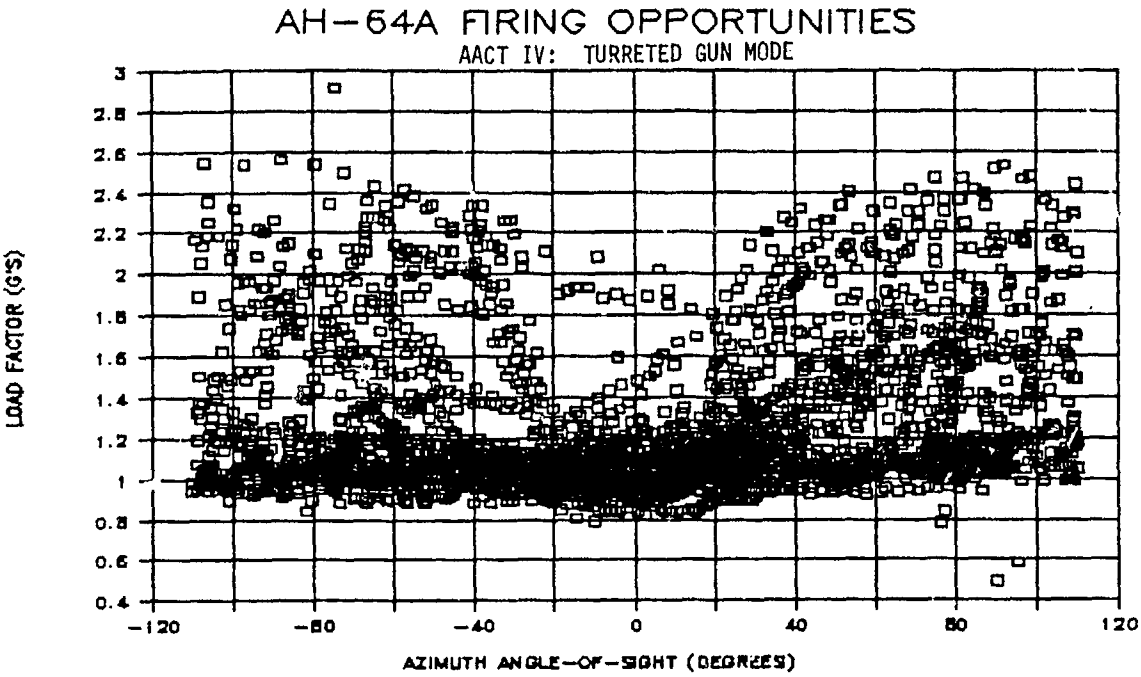


Figure 68. Cobra-to-bogey turret window angle-of-sight histograms.



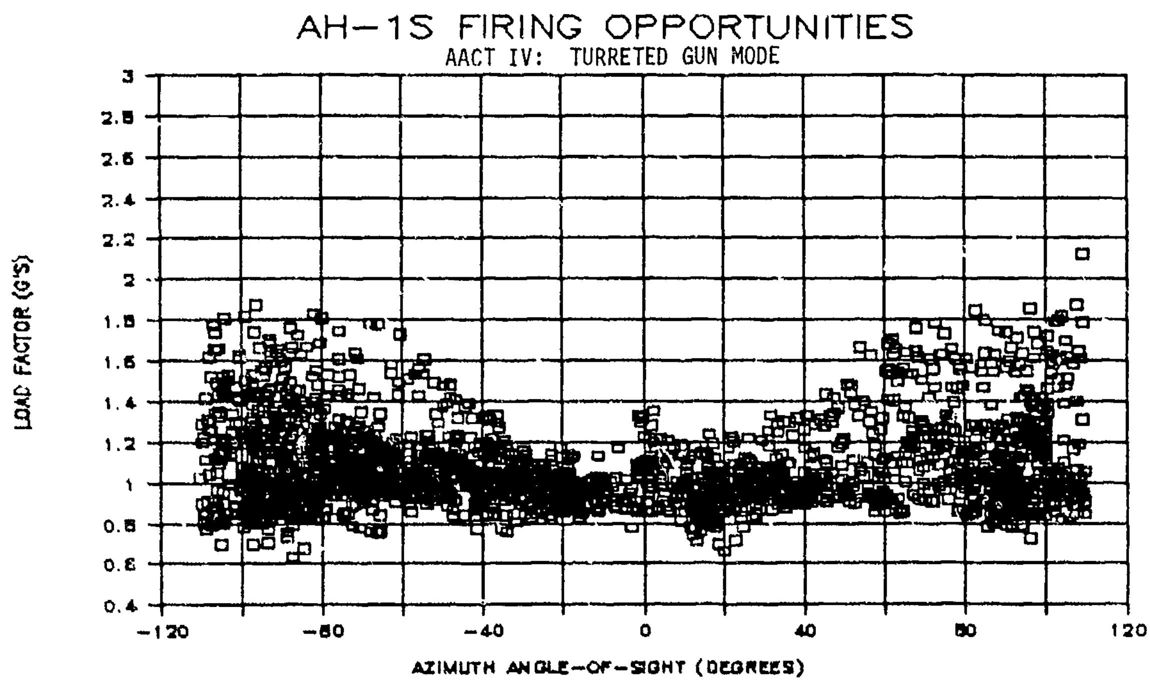
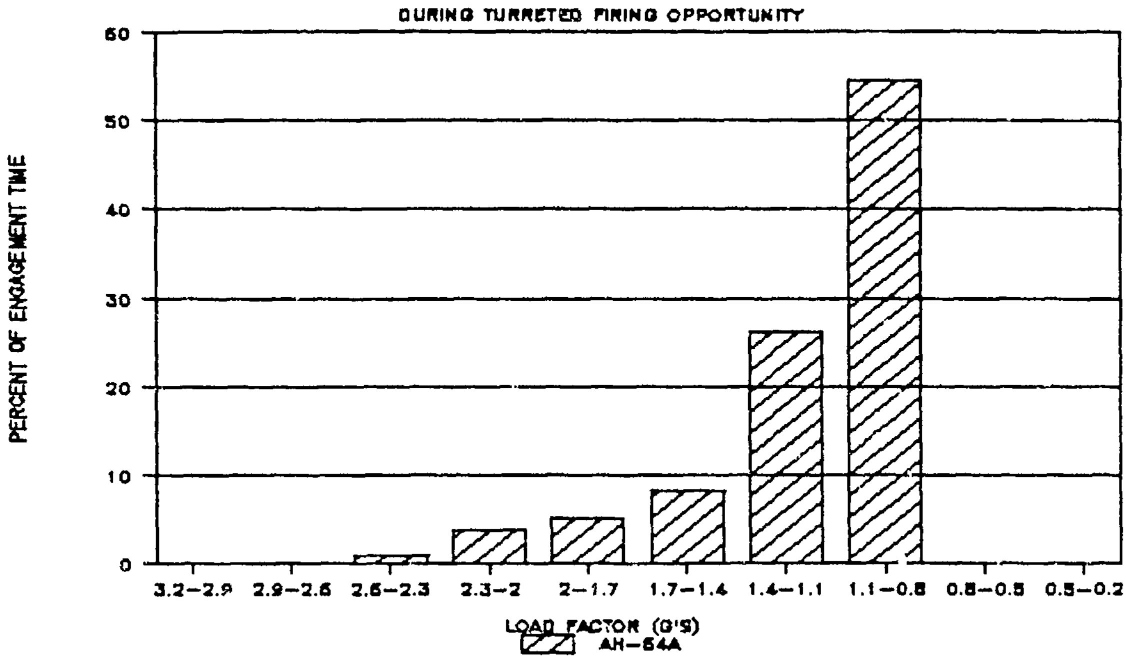


Figure 69. AH-64A and AH-1S load factor vs azimuth angle-of-sight firing opportunities.



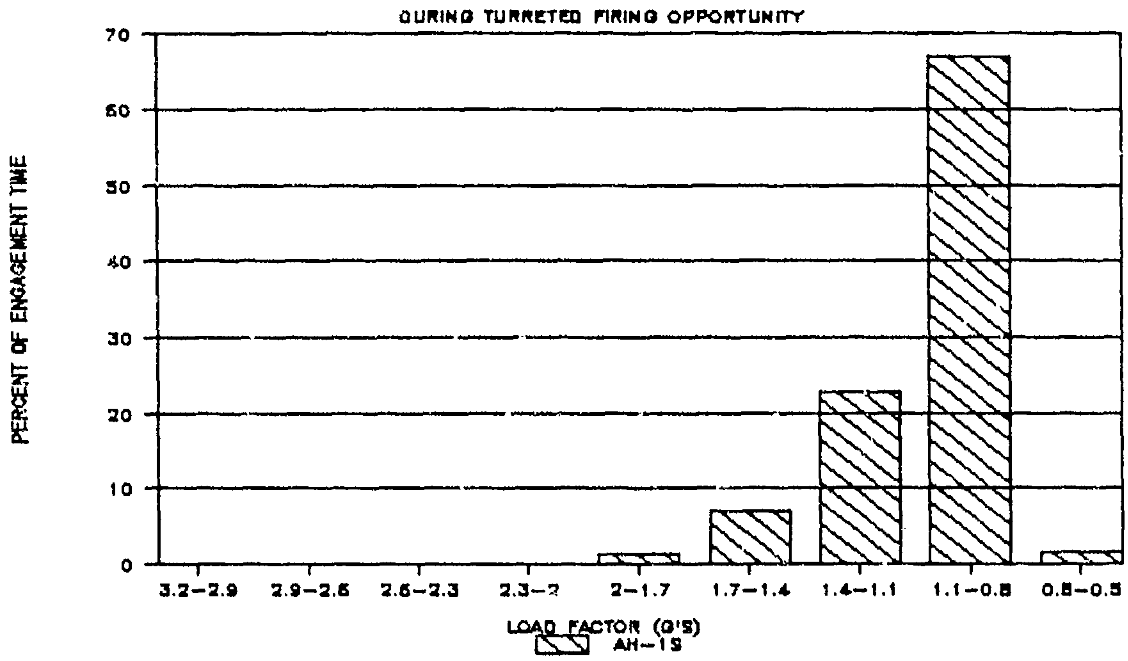


Figure 70. AH-64A and AH-1S turreted firing opportunity load factor histograms.

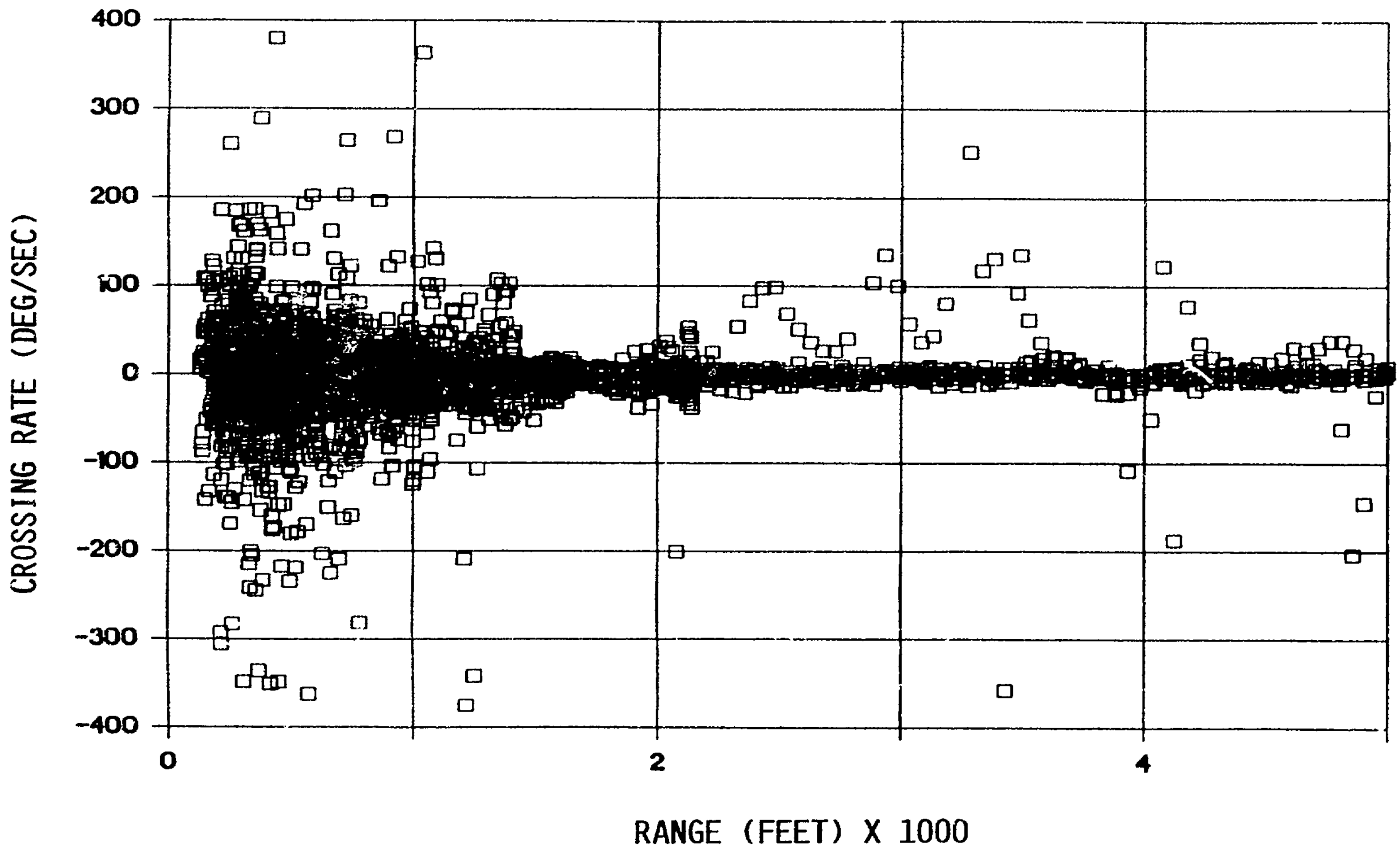


Figure 71. Crossing rates as a function of range to bogey - AH-64A vs SA-365N-1.

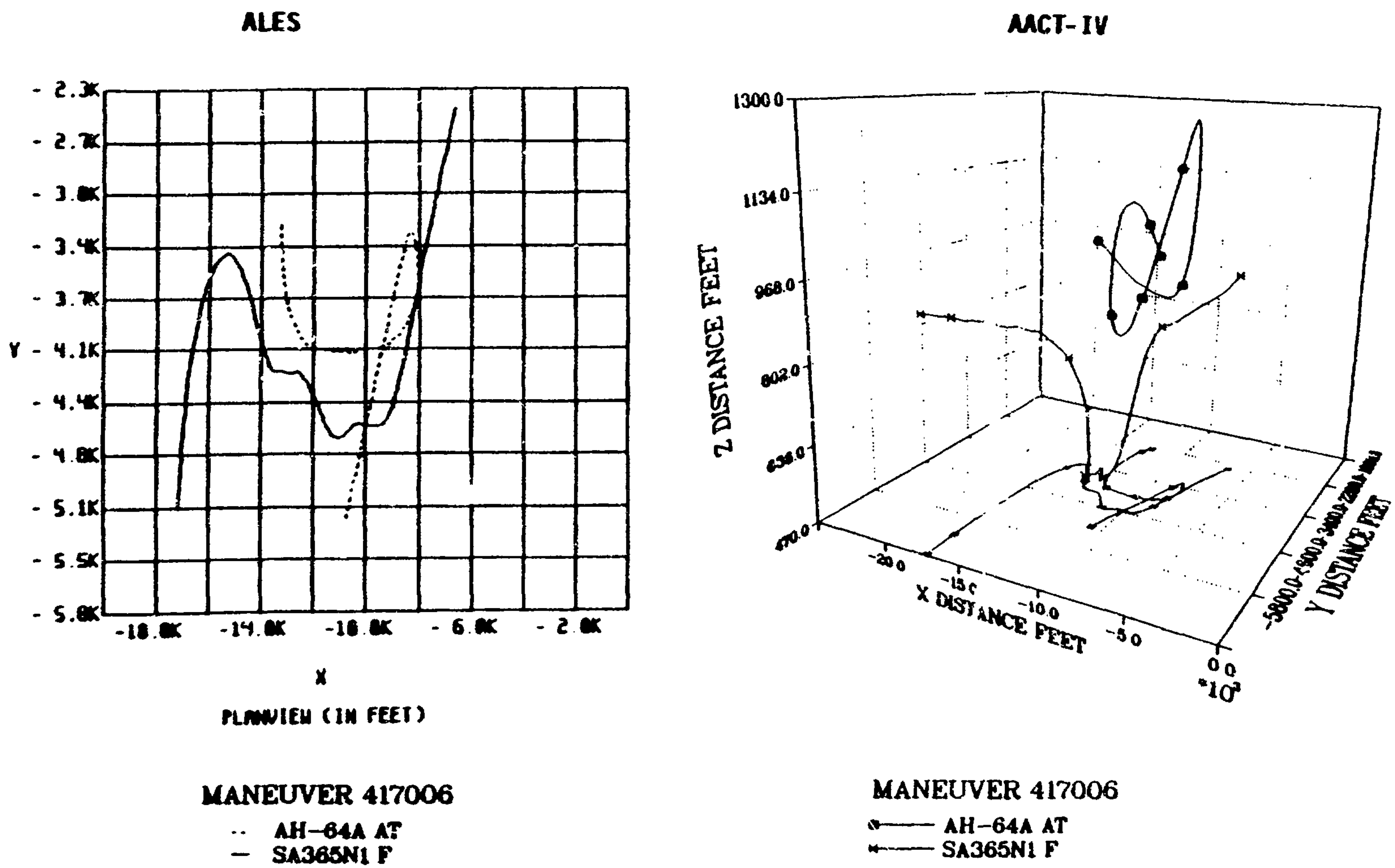


Figure 72. Re-creating AACT IV flight trajectories in ALES.

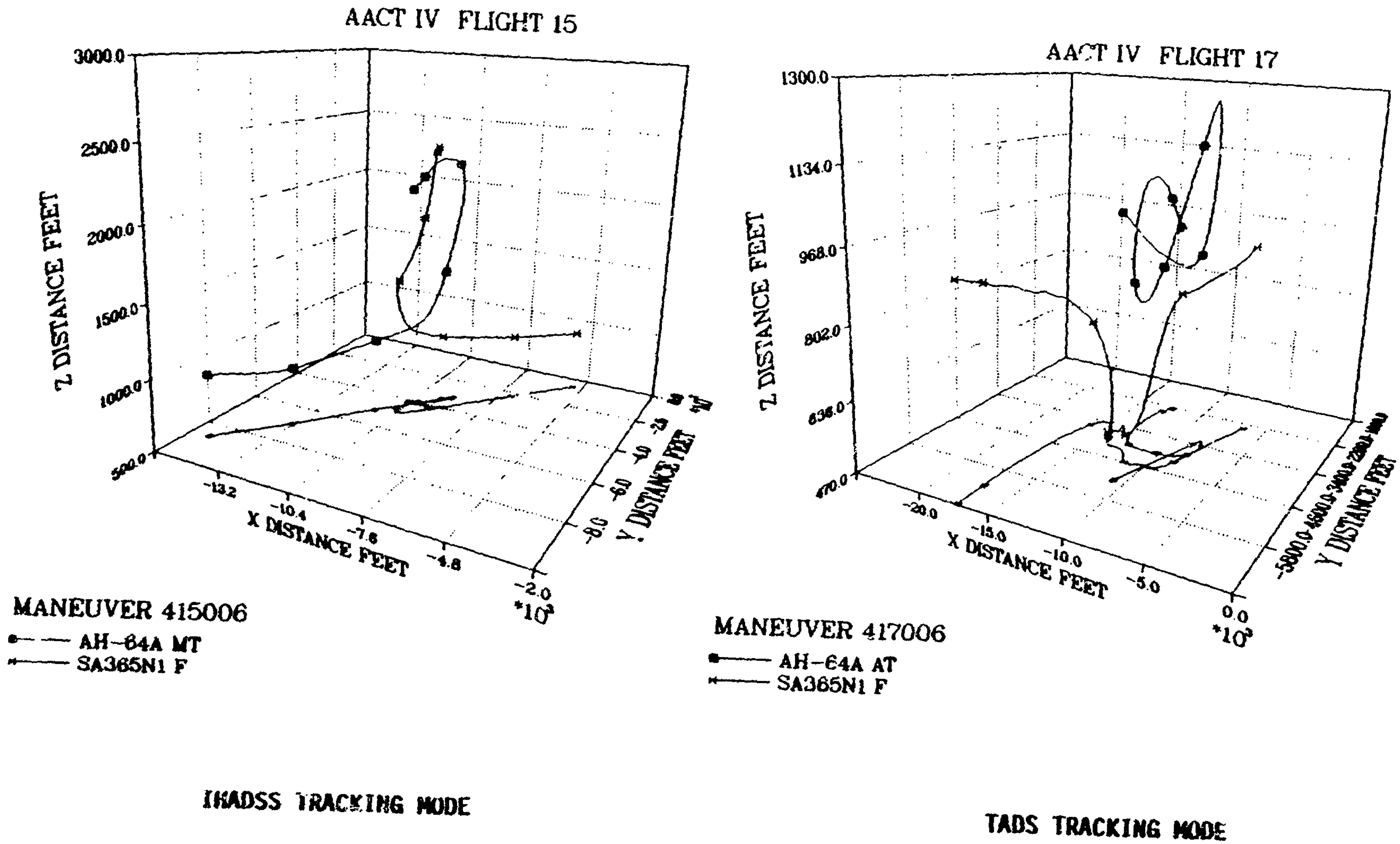


Figure 73. Maneuver trajectories for same initial conditions in both IHADSS and TADS tracking modes.

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APPENDIX A
AIRCRAFT CONFIGURATION ELEMENTS

GENERAL

The AACT IV exercise contained several aircraft configuration initiatives which served either as an integral part of the test methodology scheme or as a research objective of the flight test evaluation itself. Those initiatives may be generally categorized as either weapon simulator elements, instrumentation elements, or unique airframe elements. The weapon system simulator elements, the Saab BT-53 Laser Weapon Simulator (LWS), the Giravions Dorand DX-175 LWS, optical laser reflectors, the Polhemus Helmet Mounted Sight (HMS), the Thomson/Hamilton Standard Heads-Up Display (HUD) units, the Lucas turret, the Target Acquisition and Designation System (TADS), and the air-to-air Stinger captive flight trainer (ATAS/CFT), were employed to provide a measure of effectiveness (MOE) for the aircraft involved. The instrumentation elements, including handling qualities, performance and extensive structural parameters, onboard recording and telemetry capability, interior and exterior in-flight video recording, and ground radar space positioning, provided a broad data base from various data collection mediums. Lastly, the special airframe elements, particularly the modified ammo bay doors, ballast containers, and air data booms, helped meet specific test objectives; the stick shaker and hub spring provided an additional margin of safety; and the Fenestron directional control device offered a unique rotorcraft component to be explored in air combat maneuvering.

WEAPONS SYSTEM SIMULATOR ELEMENTS

Laser Weapons Simulators

The LWS carried on board each of the test aircraft provided a quantitative MOE of simulated one-on-one combat engagements between opponent aircraft possessing the same or similar equipment and/or capability. A Giravions Dorand DX-175 LWS was mounted on the AH-1S, SA-365N-1, and 406 CS (Figures A-1, A-2, and A-3), while a Saab BT 53 LWS was on board the AH-64A (Figure A-4). Each consisted of subassemblies designed for adaptation to a given weapon system. The advertised accuracies of these laser systems are for the DX-175, ± 5 meters in range and ± 0.7 milliradians in offset, and for the BT 53, ± 2 meters in range and ± 0.1 milliradian in offset. The LWS provides a means of accurately evaluating the effects of firing weapons against real moving targets fitted with optical reflectors (Figures A-5 through A-8) by using a harmless (i.e., eye safe) laser transmission/reflection/detection system and a computer. The LWS provides a quantitative evaluation tool for measuring engagement ranges, hit probabilities, aiming accuracies, and platform and weapon axis stability. Although ballistic characteristics exhibited by the various munitions "fired" by the LWS faithfully reproduce the ballistics of real projectiles as programmed, the simulation has not yet matured to adequately include the additional dynamics of aircraft and gun turret

rates and accelerations during aggressive air-to-air engagements, the relative wind effects during off-axis shot, nor the realism of recoil effects and vibration.

The BT-53 LWS consists of a laser tube, computer unit, gyroscope unit, video interface unit, tracer unit, control unit, and optical retroreflectors. All components are standard Saab equipment with the exception of the retroreflectors, gyroscope, and video interface units. The laser tube contains three laser transmitters operating through a gimbaled objective and a laser receiver. The computer unit computes ballistic trajectory, directs the laser transmitter to track along this path, calculates aiming and hit/miss errors, and outputs this data to recording and telemetry devices. The ballistic characteristics of the weapon simulated are input through interchangeable circuit board cards in the computer unit. The gyroscope unit provides an input of aircraft motion to the ballistic calculation, and the video interface unit combines the video picture from a gun camera (boresighted with the LWS) with numerical firing data and a simulated tracer. The control unit is used to operate the LWS and also contains a printer for hard-copy output of firing data. Hemispherical optical reflector units mounted on the sides of each aircraft reflect the laser beam back to the receiver for accurate computation of target relative position. The BT-53 was not, however, integrated with the Apache lead computing fire control system.

The DX-175 LWS consists of a control unit, optical unit, electronics unit, rate gyro unit, and video interface unit. All components are standard Giravions Dorand equipment with slight modifications for the air-to-air environment. The gyro unit was added to the DX-175 package and the laser beam scanning window was increased for the weapon simulation in air-to-air combat. The DX-175 is similar to the BT-53 in many respects. The system computes ballistic trajectory, directs the laser transmitter to track along this path, calculates aiming and firing errors, and outputs this data to the appropriate devices. The ballistic characteristics are stored on cassettes which are integrated into the systems. The gyro unit provides an input of aircraft motion to the ballistic calculation and the video interface unit combines the video picture from the gun camera with numerical firing data and a simulated tracer.

Helmet-Mounted Sights

The AH-1S, AH-64A, and 406 CS aircraft were each equipped with HMS integrated with the turreted "gun" LWSs. The AH-1S and 406 CS were modified for the Polhemus Navigation Sciences (PNS) electromagnetic HMS while the AH-64A used the standard Apache Integrated Helmet and Display Sight System (IHADSS) display with either the Apache fire control computer (FCC) or LWS FCC option.

The Polhemus HMS system incorporates a new (i.e., designed for AACT IV) helmet-mounted light emitting diode (LED) matrix sight unit (Figure A-9) and associated driver electronics that, in conjunction with an LWS mounted on the turret, provide a means for the HMS system to project a simulated bullet miss distance display on the pilot's monocular eyepiece. This display cues the pilot to the correct lead angle to "hit" the

target. The PNS HMS, Figure A-10, replaces standard mechanical linkage helmet sight systems standard on the AH-1S. Custom electronics enable the system to close the turret servo loop and cause the turret to track the pilot's LOS. A summary of the HMS system description, installation, operation, and testing is contained in a PNS report.*

The Apache IHADSS determines the crew member's head LOS with respect to the helicopter's armament datum line and provides this information to the fire control system. The IHADSS consists of two separate systems: the Helmet-Mounted Display (HMD) and the Helmet-Mounted Sight (HMS). The HMD provides the display of the selected sensor video and/or symbology to the crew members. The HMS subsystem provides helmet LOS information, independently for both crew stations, to the fire control system for sensor pointing and weapons aiming. The IHADSS/HMD was used in both gun modes of operation: fixed turret and moving turret. In the fixed turret mode in which the gun was constrained to zero azimuth/elevation, the IHADSS saw limited use. In the moving turret mode, the gun was slaved to the selected LOS within the standard Apache IHADSS directed turret slew limits. In neither of these modes was the FCC used to calculate ballistic corrections. The LWS used the Ballistics Research Laboratory's (BRL's) ballistics tables to calculate target hit/miss data. The LWS hit/miss data was used to position a special impact reticle on the displays. The impact reticle represents where the rounds are when they cross the target normal plane. In the fixed gun mode, the pilot flies the aircraft to place the impact reticle on the target. In the moving turret mode, the crewman with control of the gun moves the LOS to place the impact reticle on the target.

However, in the case of fixed gun aiming, the HMD with stabilized fixed forward reticle was unsatisfactory to the MDHC pilot and thus saw only limited use. Since the fixed gun mode represents a second or third order degenerated mode for the AH-64A weapon system, the IHADSS aiming system is not particularly acute in this regime. The limited angular resolution of the sight system does not lend itself to fixed gun application. IHADSS uses 4 degrees of freedom only (i.e., no lateral or longitudinal). Without the additional lateral and/or longitudinal spatial orientation, corrections to the aiming reticle for head alignment, lateral or longitudinal movement, or repositioning from a set boresight position for the stabilized reticle would introduce errors in the aiming task. In view of the above shortcomings, the pilot opted to introduce manually boresighted grease pencil cross-hairs on the blast shield and the CPG wind screen for rudimentary fixed gun aiming.

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*DeRuyck, A.R., AH-1S Air Combat (ACM) Helmet Mounted Sight (HMS) System Summary Report, Polhemus Navigation Sciences, Colchester, Vermont, unpublished, January 1988.

A modified mode of weapon system operation was also implemented by MDHC. In this mode the AH-64A FCC ballistic calculations were modified to match the LWS ballistic tables. The FCC used the LWS target range data in place of normal TADS laser range in the BRL ballistic equations. The LWS used the BRL ballistic tables to calculate target hit/miss data. The CPG was able to use IAT in this mode of operation. The selected LOS could be either TADS or IHADSS. The TADS and gun were always slaved to the selected LOS in this mode. The crewman with control of the gun places the LOS reticle on the target, then fires the gun while maintaining the LOS reticle on the target. The FCC positions the gun so the rounds will hit the aim point.

Heads-Up Display Units

The active HUD units used during AACT IV were employed on the SA-365N-1 and 406 CS aircraft only, as shown in Figures A-11 and A-12. Although the AH-1S is fitted with a HUD, it was not activated for the test due to the unavailability of proper interface electronics. Both HUDs used were Thomson-CSF/Hamilton Standard units. One was used strictly by the 406 CS for the Stinger CFT engagements. The 406 CS had the stowable HUD arrangement mounted from the overhead at the pilot's station. When the HUD is not in use, it can be pivoted up and behind the pilot's station. The HUD installed on the SA-365N-1 was rigidly fixed at the pilot's station and was integrated with the "fixed gun" LWS.

The function of both HUDs was to provide an aiming reticle for the pilot. Neither unit transposed any aircraft performance or state parameters onto the HUD screen. The HUD on the SA-365N-1 was programmed to integrate the aiming error and hit/miss data received from the "gun" LWS to generate a lead pipper. The pilot would maneuver the aircraft while firing the LWS to put the cross-hair reticle over the target lead pipper. This lead correction would theoretically put ballistically computed bullets on the target. The 406 CS PDU, as linked to the Stinger interface electronics, emulated the operation of the basic ATAS system reticle symbology, including the aural tone for target acquisition, lock, and tracking evaluation.

Turrets

Gun turrets were employed on three of the four AACT IV aircraft; the SA-365N-1 was flown with "fixed gun" capability only. LWSs were mounted to each turret with the full slew articulation available. For the AH-64A the mechanical turret limits are ± 110 degrees azimuth and +11, -60 degrees elevation, and for the AH-1S, ± 110 degrees azimuth and +13, -50 degrees elevation. The standard ship system 20mm and 30mm turrets for the AH-1S and AH-64A, respectively, were used (Figures A-13 and A-14). The 406 CS aircraft was specially modified to accommodate a compact, lightweight Lucas hydraulically actuated gun turret drive assembly (Figure A-15). A Giravions Dorand LWS was fitted to the Lucas turret with a Polhemus electromagnetic HMS to direct the movement of the "gun" through the full ± 90 degrees azimuth plus 60 degrees elevation.

Air-to-Air Stinger/Captive Flight Trainer

An OH-58C/D qualified ATAS missile system was installed in the 406 CS and a Stinger CFT missile was mounted on the left weapon pylon as shown in Figure A-16. The CFT system includes the launcher, launcher adapter, coolant bottle, heads-up PDU, and interface electronics. The missile itself contained only the IR seeker head and no propellant. The missile seeker head was boresighted with, and targets were engaged through, the PDU. The first detent on the cyclic fire control grip enabled the auto uncage mode of the seeker. A moving reticle and acquisition aural tone followed if target lock was attained.

INSTRUMENTATION ELEMENTS

The instrumentation packages for each of the AACT IV helicopters recorded basic aircraft state and performance data (see Figures A-17 through A-25). In addition, the AH-1S, AH-64A, and 406 CS were extensively instrumented for structural loads. Each aircraft had both PCM onboard recording and telemetry capability. The complete lists of instrumented parameters for the AH-1S, AH-64A, SA-365N-1, and 406 CS are contained in Reference 3. An LWS video monitor was part of the cockpit instrumentation package in the AH-1S and SA-365N-1 to provide LWS boresight, laser bullet trajectory, and hit/miss data presentation. Aircraft pilot/copilot stations are shown in Figures A-26 through A-32. In addition, each aircraft was equipped with a unique main rotor slip ring assembly to transfer data signals from the rotating components to the fixed data recording system (see Figures A-33 through A-36).

Video cameras were used extensively on each of the AACT IV aircraft to record what the pilot was seeing (forward), what the gun was seeing, and in one case on the AH-64A, the view directly aft (i.e., the "6 o'clock" position). The video pictures from each of the cameras were recorded onboard the respective aircraft with the gun camera image telemetered to the ground. The AH-1S carried a fixed forward wide-angle camera mounted at the nose and a camera mounted on the turret, boresighted with the LWS, which had the LWS cross-hair, tracer, and hit/miss information superimposed on the video picture. The AH-64A was equipped with a camera inside the cockpit (over the pilot's shoulder), a camera outside the cockpit (above and behind the pilot's canopy), and a special mini camera in the vertical tail (in place of the aft navigation light) looking aft. In addition, the TADS/PNVS FLIR and television images, with tracer and miss distance symbology transposed, were available for the turreted and fixed forward guns. The SA-365N-1 had a single fixed forward camera mounted on the left side of the aircraft just below the fixed LWS. LWS symbology was transposed onto the video. The 406 CS had an exterior fixed forward camera located on the cabin roof above the copilot's head, a "gun" camera on the turret boresighted with the LWS for laser hit/miss data display, and a special PDU camera to record the Stinger missile CFT symbology.

AIRFRAME ELEMENTS

Ammo Bay Doors

In order to accommodate the vast array of data channel measuring equipment, recording devices, and interface electronics onboard the AH-1S helicopter, unique modifications to both ammo bay doors were made to increase the contiguous volume of the ammo bay. A "bulged" fiberglass shell was molded and affixed to the basic door frame of two doors with interior hard-points added to facilitate the mounting of electronic hardware (Figures A-37 and A-38). The door modifications added an additional 3 cubic feet of usable volume but contributed no perceptible degradation to basic AH-1 aerodynamics or performance.

Ballast Containers

Additional ballast weight was required for the SA-365N-1 to bring its test gross weight up to the 95% fraction of maximum gross weight established for all AACT IV aircraft. The ballast (800 lbs of lead bars) was distributed between two heavy gauge aluminum boxes bolted and cabled to the mid cabin and aft cargo hold floor mounts as shown in Figures A-39 and A-40.

Air Data Booms

The aircraft airspeed booms or air data booms for obtaining angle of attack, angle of sideslip, airspeed and altitude data were installed by each of the respective airframe manufacturers; the AH-64A did not use a special flight test airspeed appendage but rather used the standard ship air data sensor system (ADSS) equipment. The data booms for the SA-365N-1 and 406 CS conformed to previous standard installations (see Figures A-41 and A-42). The AH-1S boom, Figure A-43, was installed by BHTI as per AATD requirements in an atypical location and at a somewhat shorter length (relative to previous installations and the rotor tip path plane boundary). The primary driver for this arrangement was to permit the turreted LWS a clean scanning FOV throughout the normal turret slew limits. A thorough airspeed calibration test of the AH-1 data boom is required to quantify the impact this particular installation has on air data.

Stick Shaker

A collective stick shaker was installed in the AH-1S pilot station as a tactile indicator of the exceedance of a preset engine torque (see Figure A-44). The shaker activation threshold was set at 98% engine torque but was later lowered to 85% at the request of the pilot after several ACM flights in order to give a larger overtorque warning margin. Although the addition of the stick shaker to the collective stick increased the stick force felt by the pilot and the moment required by the friction lock to hold the collective in place, it did not present any unusual problems. In fact, the presence of the shaker was

welcomed by the pilot and it was regarded as a valuable governing device to prevent engine overtorques in the active ACM environment.

Cockpit Modifications

To improve the FOV from the 406 CS cockpit, a smaller instrument panel was installed along with wedged crew door windows and clear Plexiglas skylights.

Hub Spring

The AH-1S was retrofitted for this test with the developmental hub spring system. The hub spring system or kit included not only the hub spring mast and hub attachment hardware but also a K-flex engine driver shaft, a zero-flight-time thick wall main rotor mast, a low-g (<0.5) warning system, and a modified roll channel stability and control augmentation system (SCAS) module. The hub spring consists primarily of passive rubber composition bumpers affixed to the mast that are contacted by the rotor hub as it flaps through angles greater than 4 degrees (see Figure 45).

Fenestron

The Fenestron, the unique shrouded tail rotor of the SA-365N-1 as shown in Figure A-46, offered a novel directional control device for evaluation of its performance and durability in air combat maneuvering. The Fenestron is a component of the HH-65A, the Coast Guard version of the SA-365N helicopter. Beyond the fact that the 11-metal-blade fan-in-fin Fenestron enhanced safety when maneuvering at low altitude, when making rapid deceleration landings, or when operating around ground personnel, the lack of susceptibility to damage due to full pedal inputs by the pilot in extreme maneuvering situations and the demonstrated yaw control authority provide additional advantageous ACM characteristics.

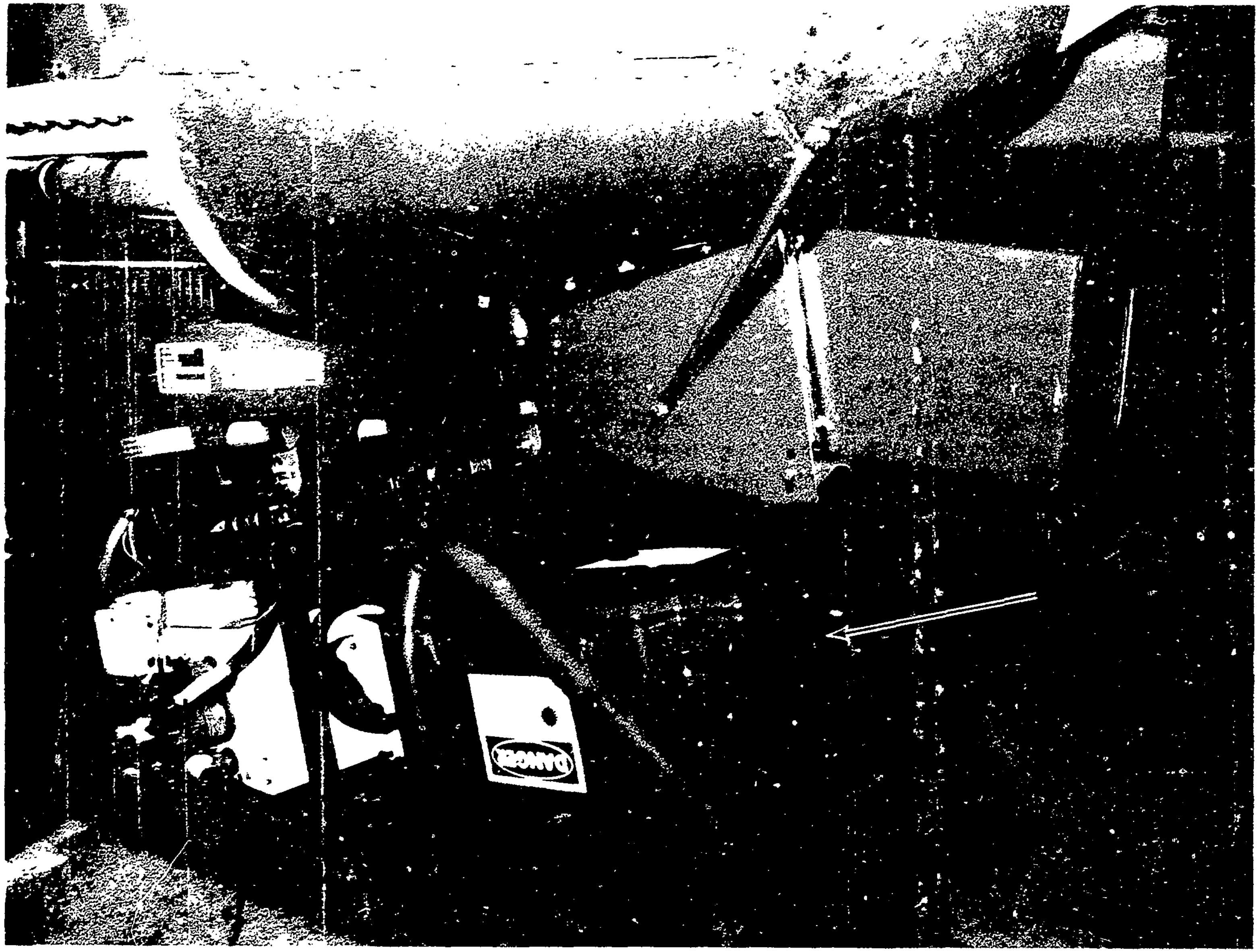


Figure A-1. DX-175 laser weapons simulator mounted on Cobra turret.

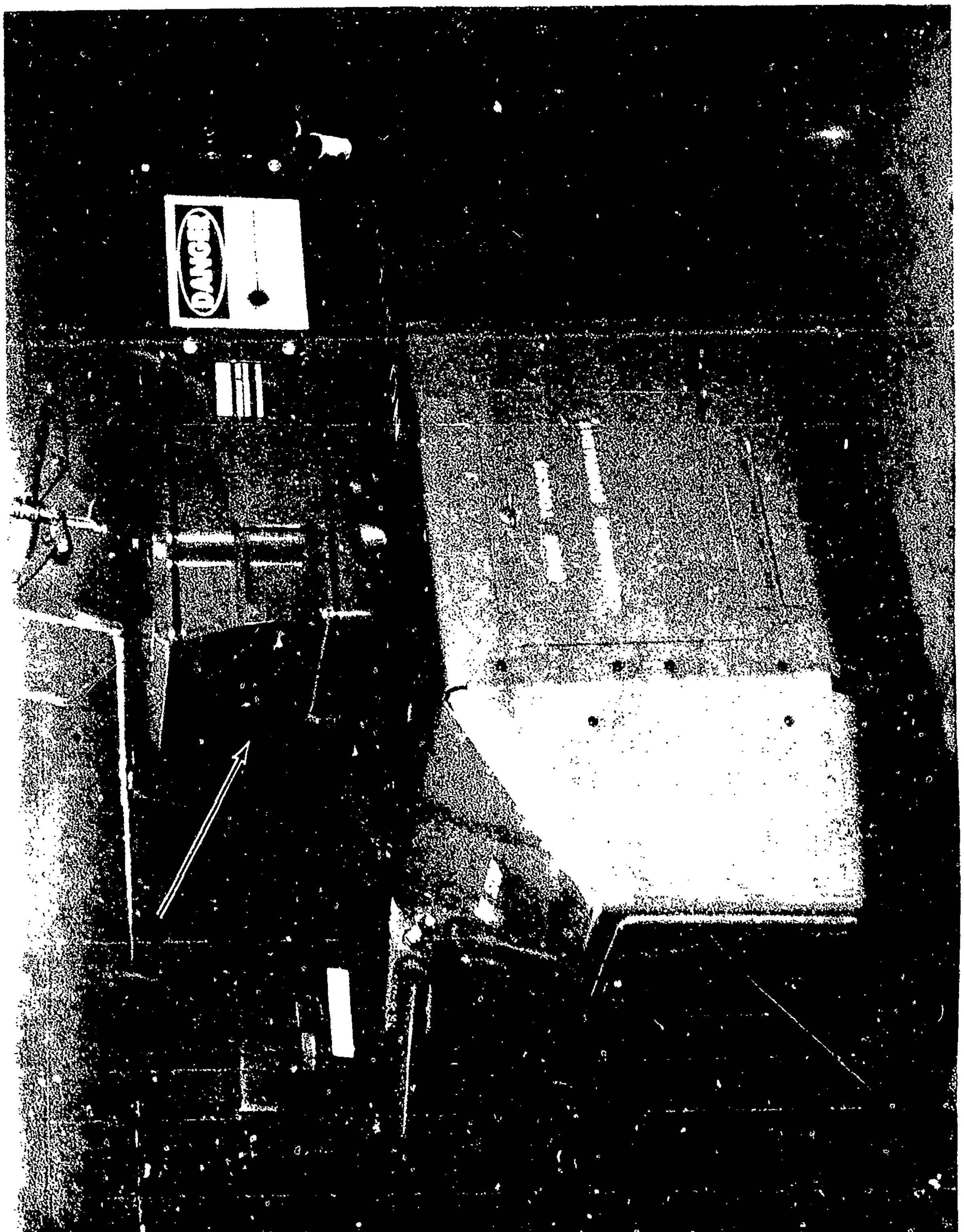


Figure A-2. DX-175 laser weapons simulator mounted on left side of Dauphin.

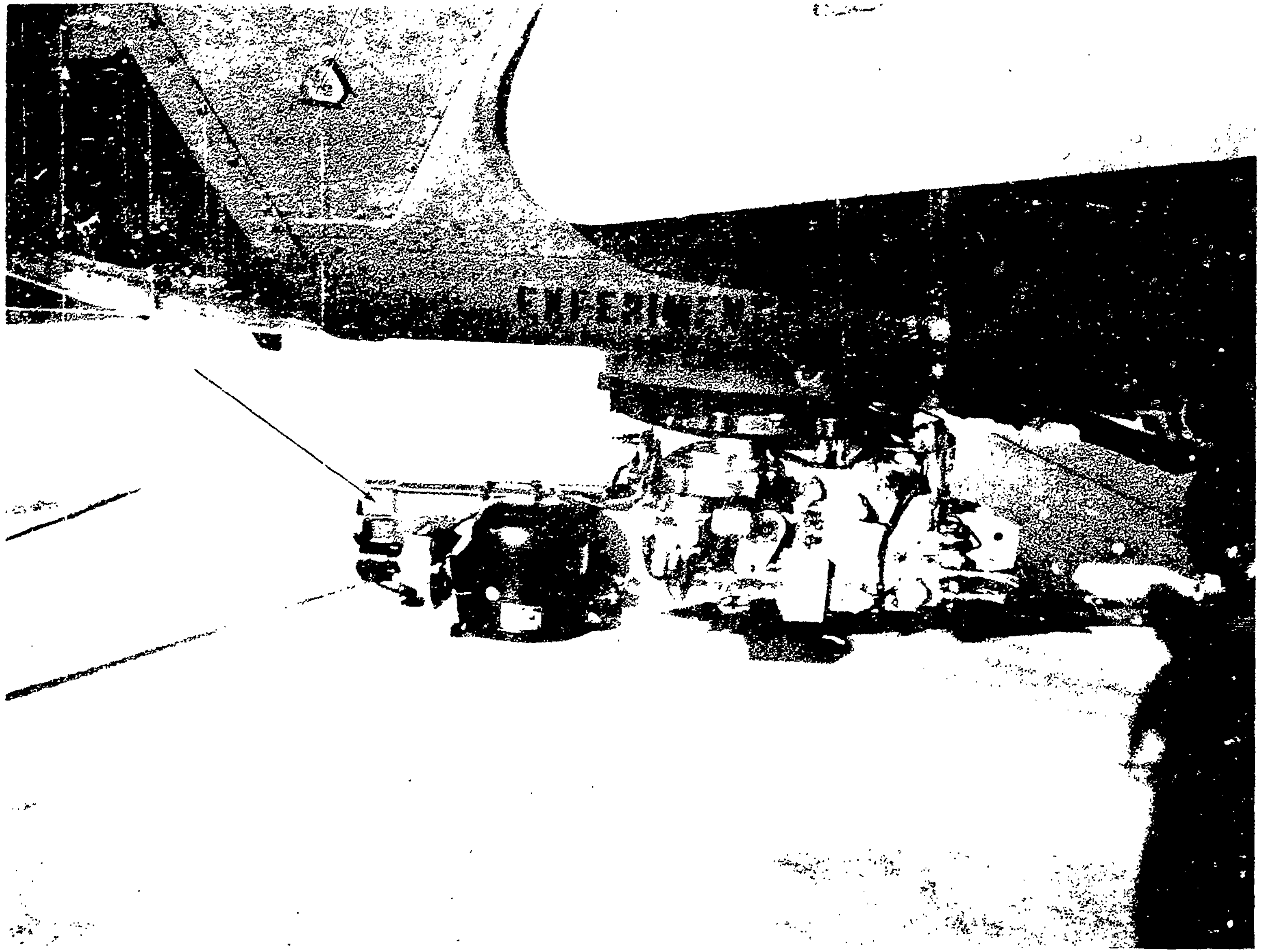


Figure A-3. DX-175 laser weapons simulator mounted on 406 CS turret.

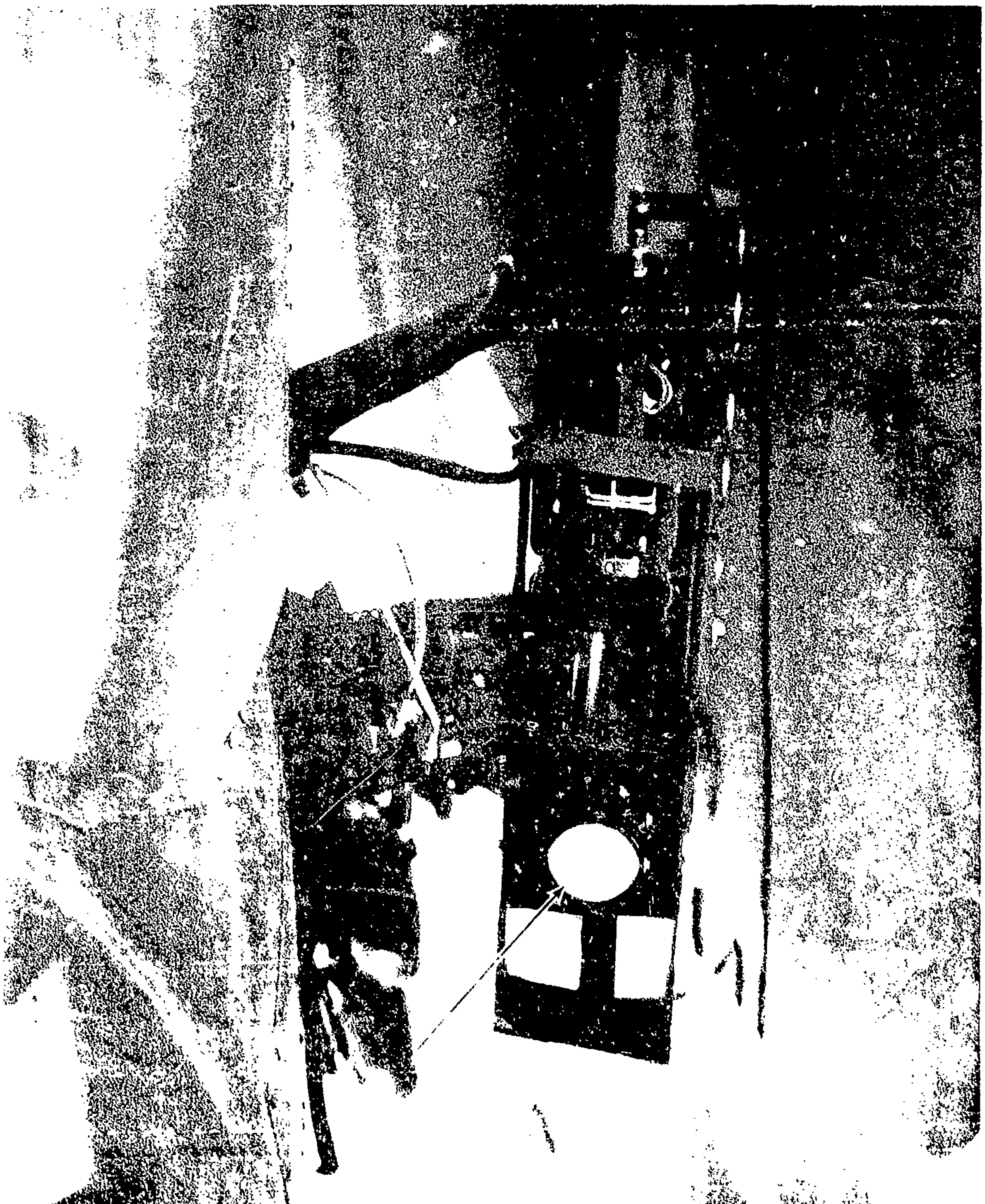


Figure A-4. BT-53 laser weapons simulator mounted on Apache turret.

Figure A-5. Laser optical reflector on AH-1S.

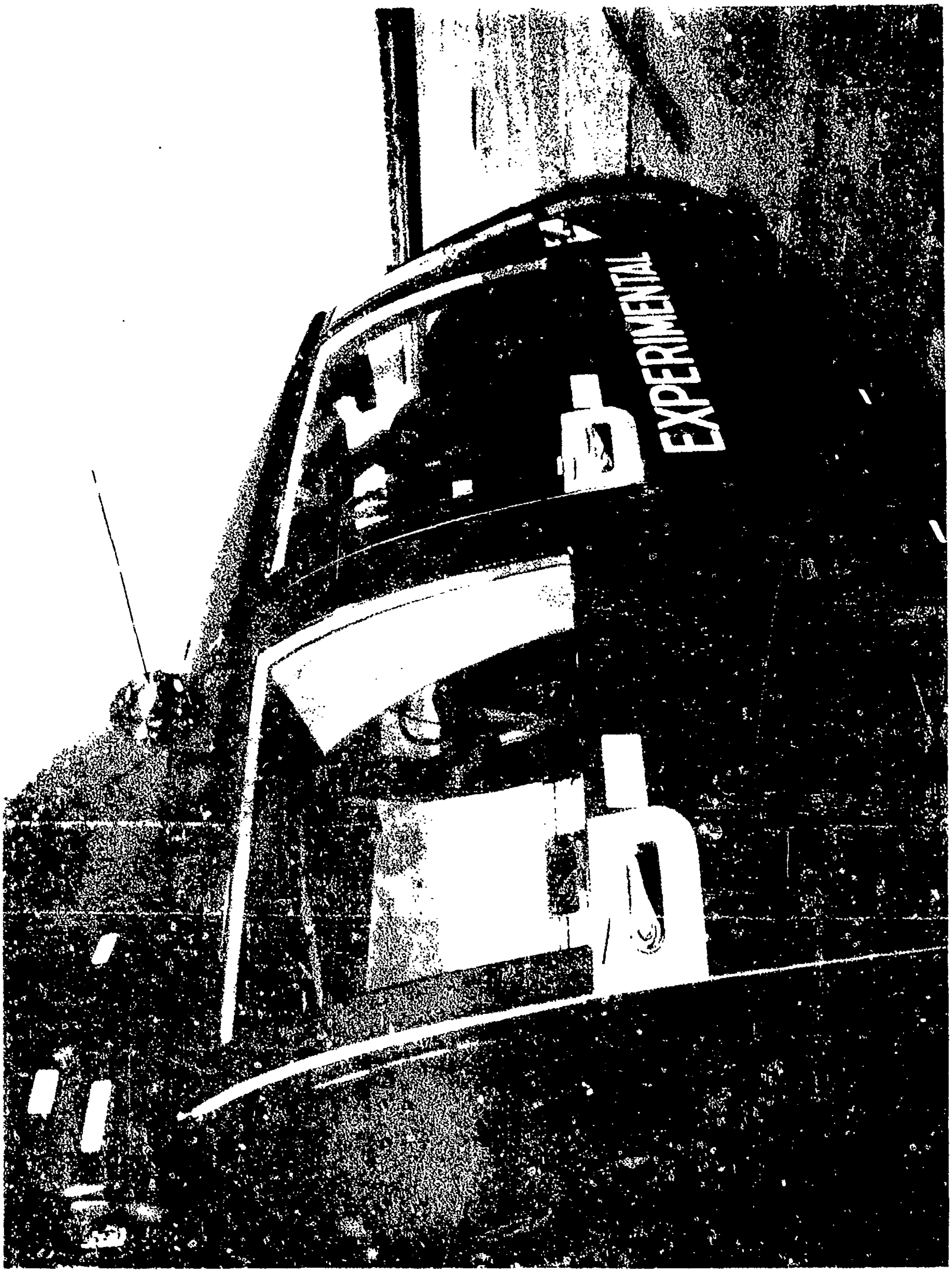


Figure A-6. Laser optical reflector on SA-365N-1.

Figure A-7. Laser optical reflector on 406 CS.

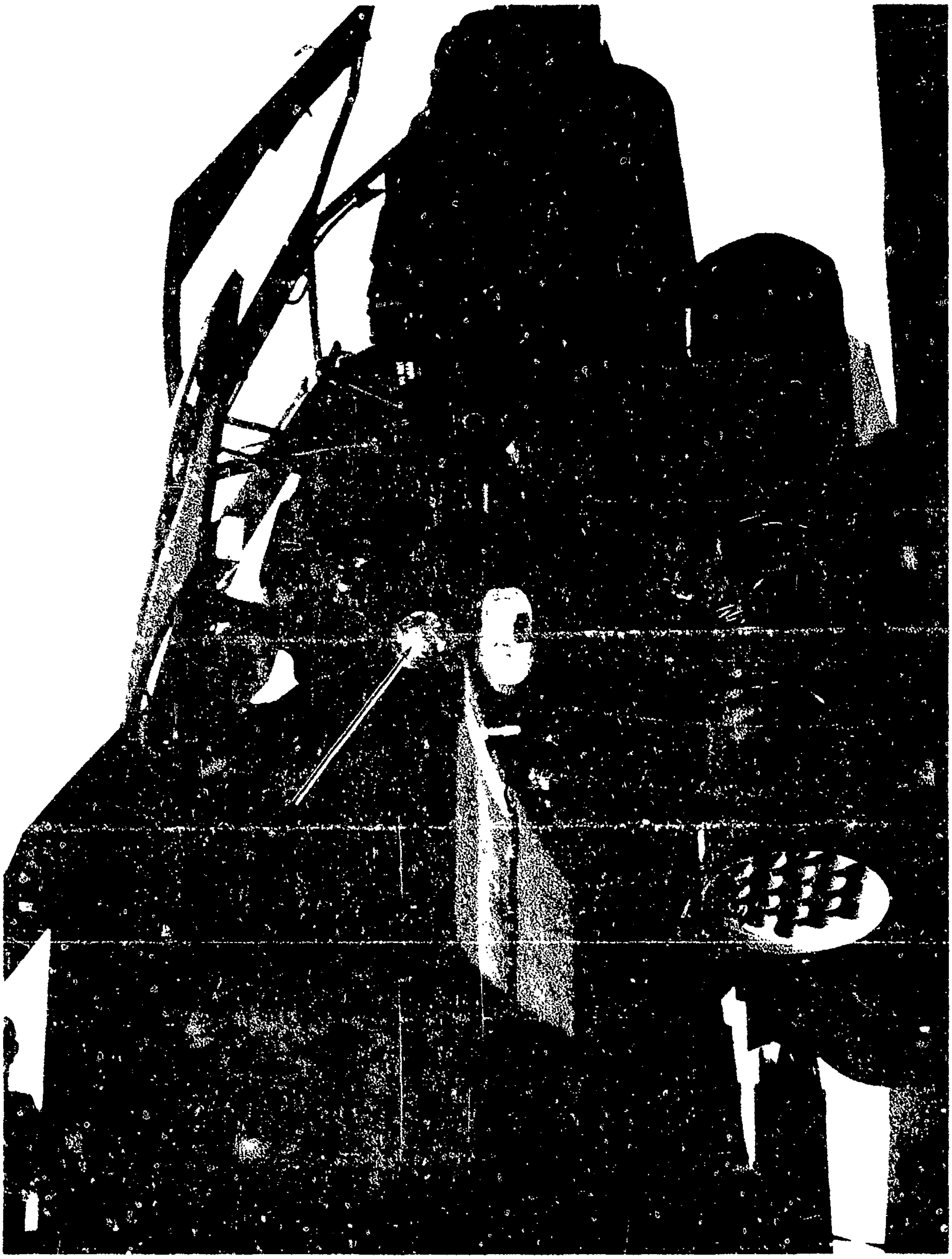


Figure A-8. Laser optical reflector on AH-64A.

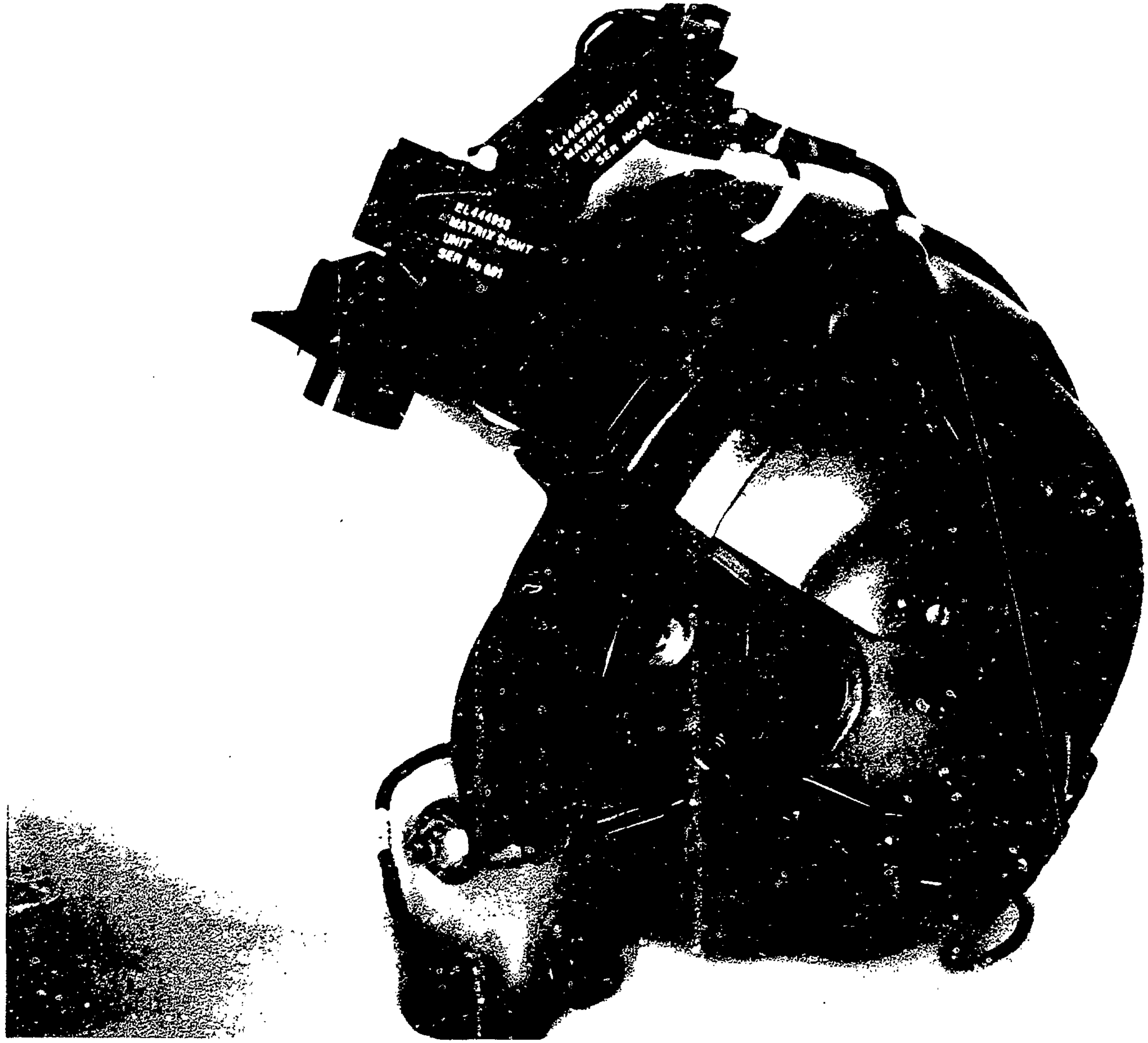


Figure A-9. Polhemus electromagnetic helmet-mounted sight (AH-1S).

Figure A-10. Helmet-mounted sight as employed in AH-1S (emitter unit bonded to canopy).

Figure A 11. Heads up display mounted above pilot station of SA 365N 1.

Figure A-12. Heads-up display mounted above pilot station of 406 CS.

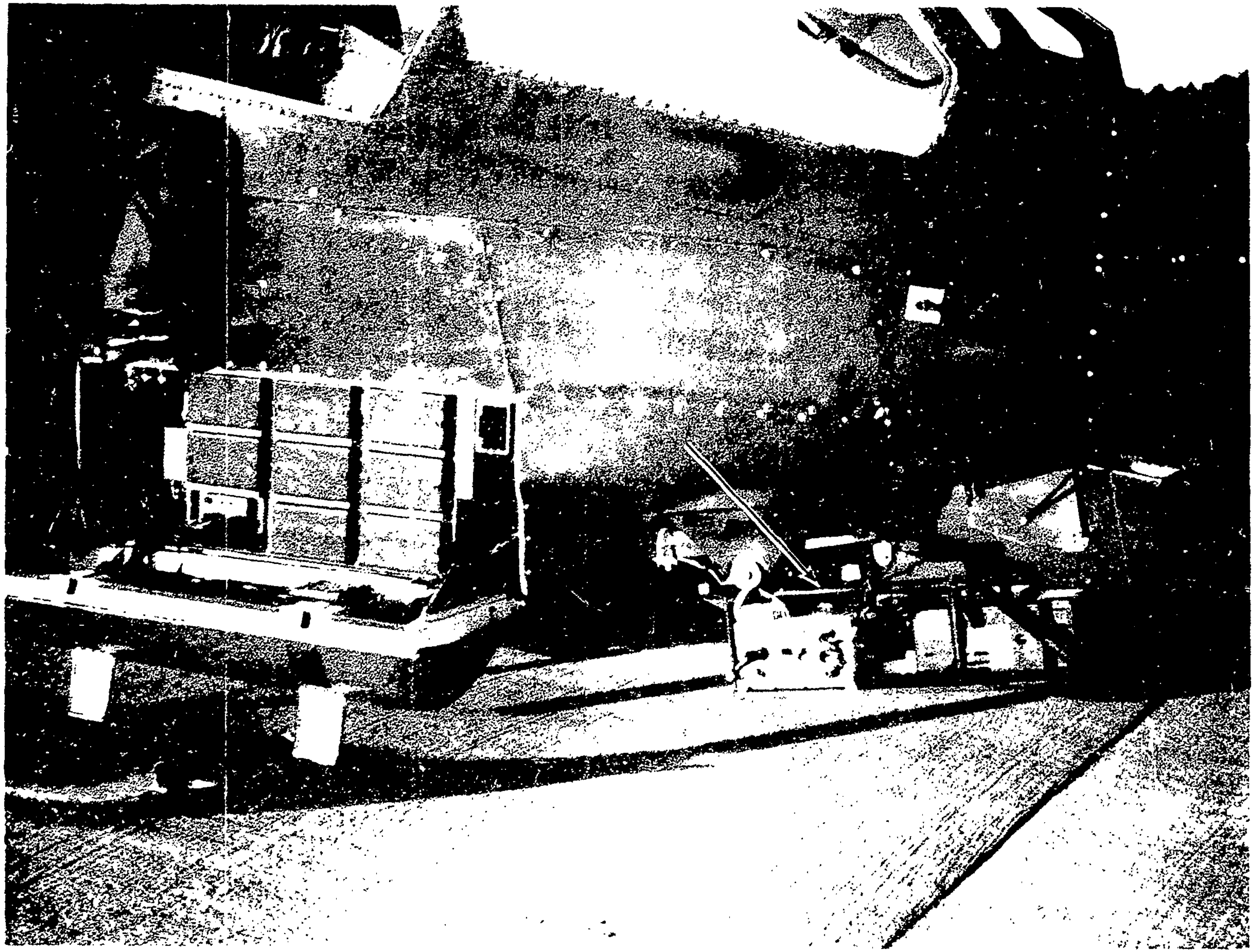


Figure A-13. Laser weapons simulator, AH-1S turret assembly.

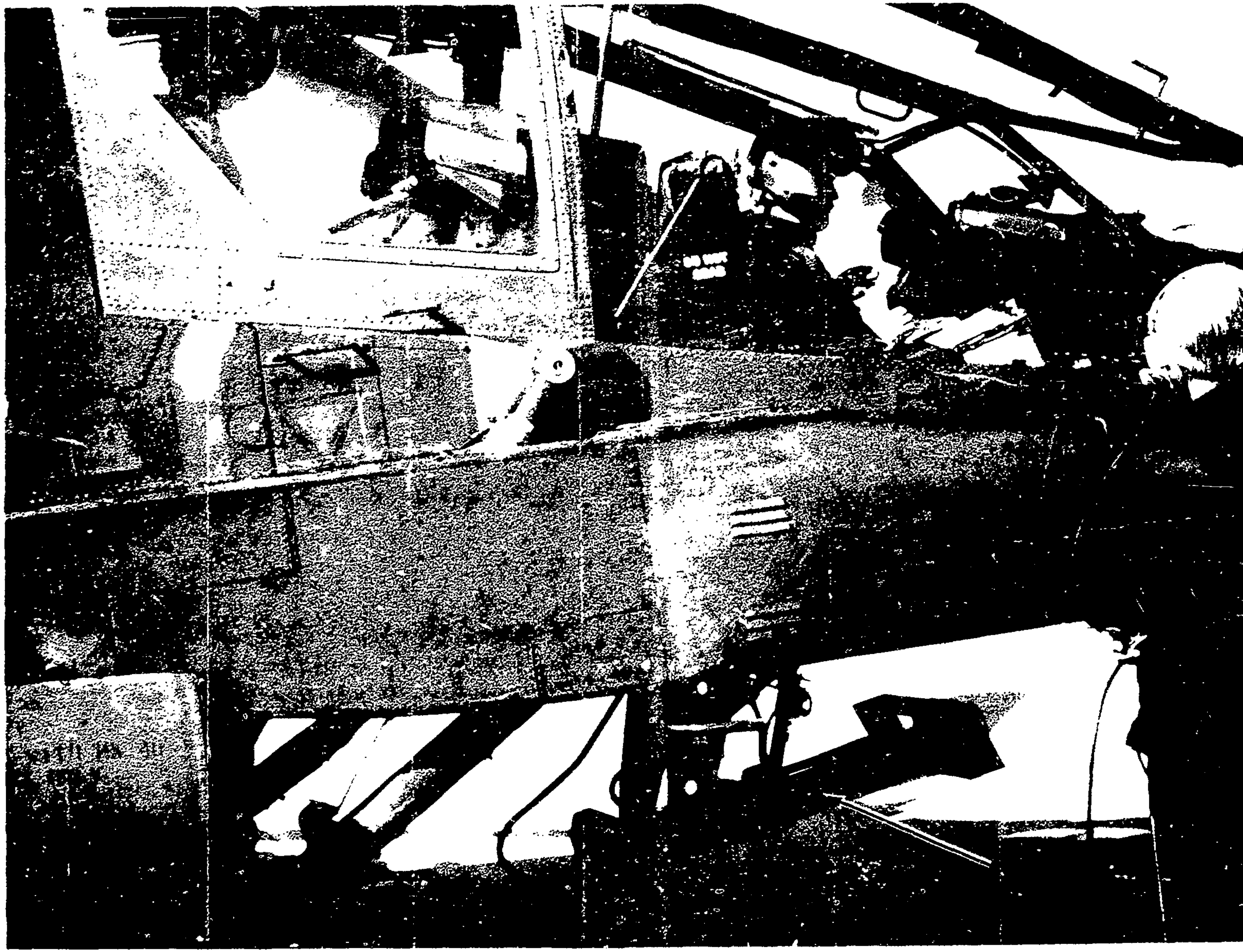


Figure A-14. Laser weapons simulator, AH-64A turret assembly.

Figure A-15. Laser weapons simulator, 406 CS turret assembly.

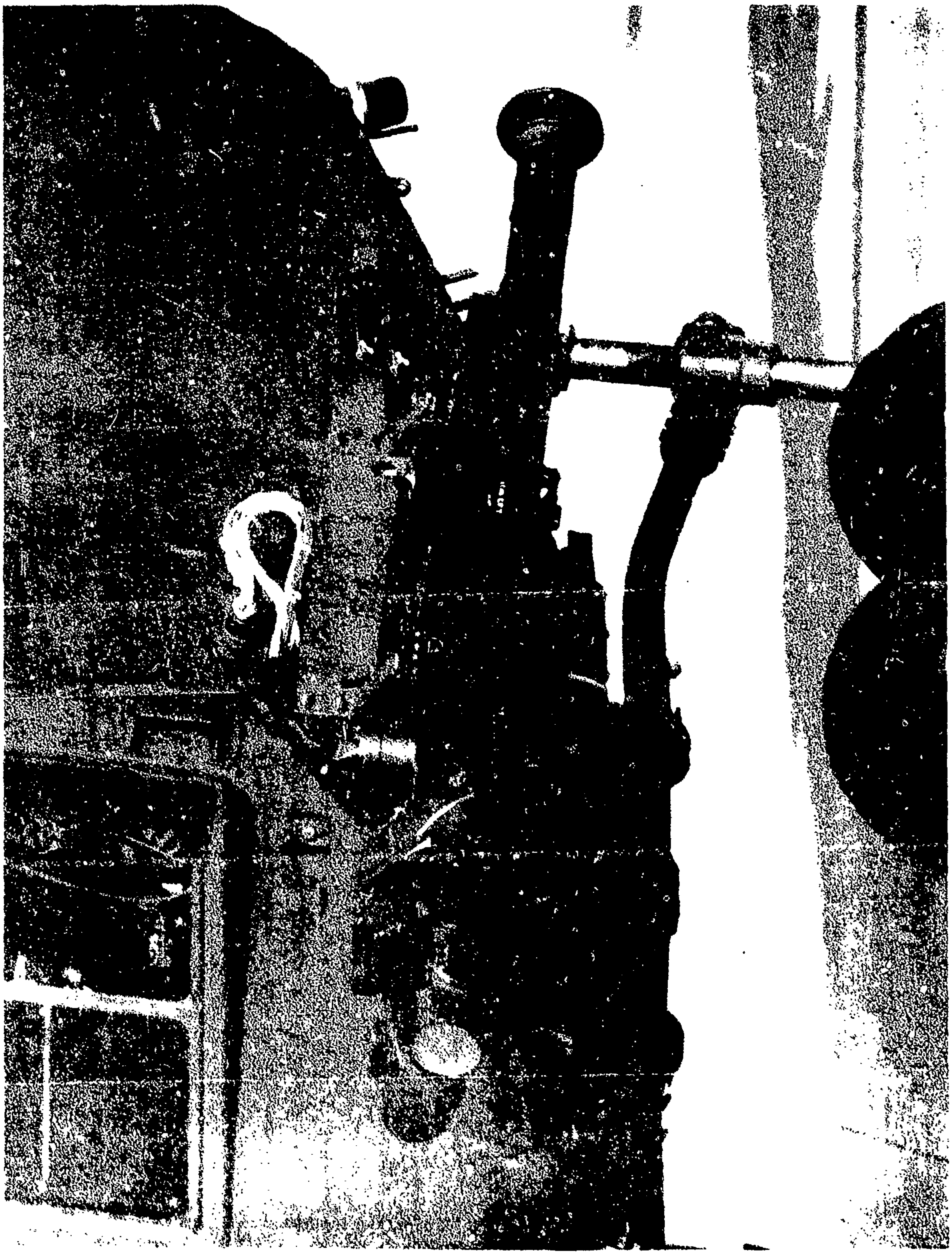


Figure A-16. Air-to-air Stinger missile captive flight trainer mounted to 406 CS.

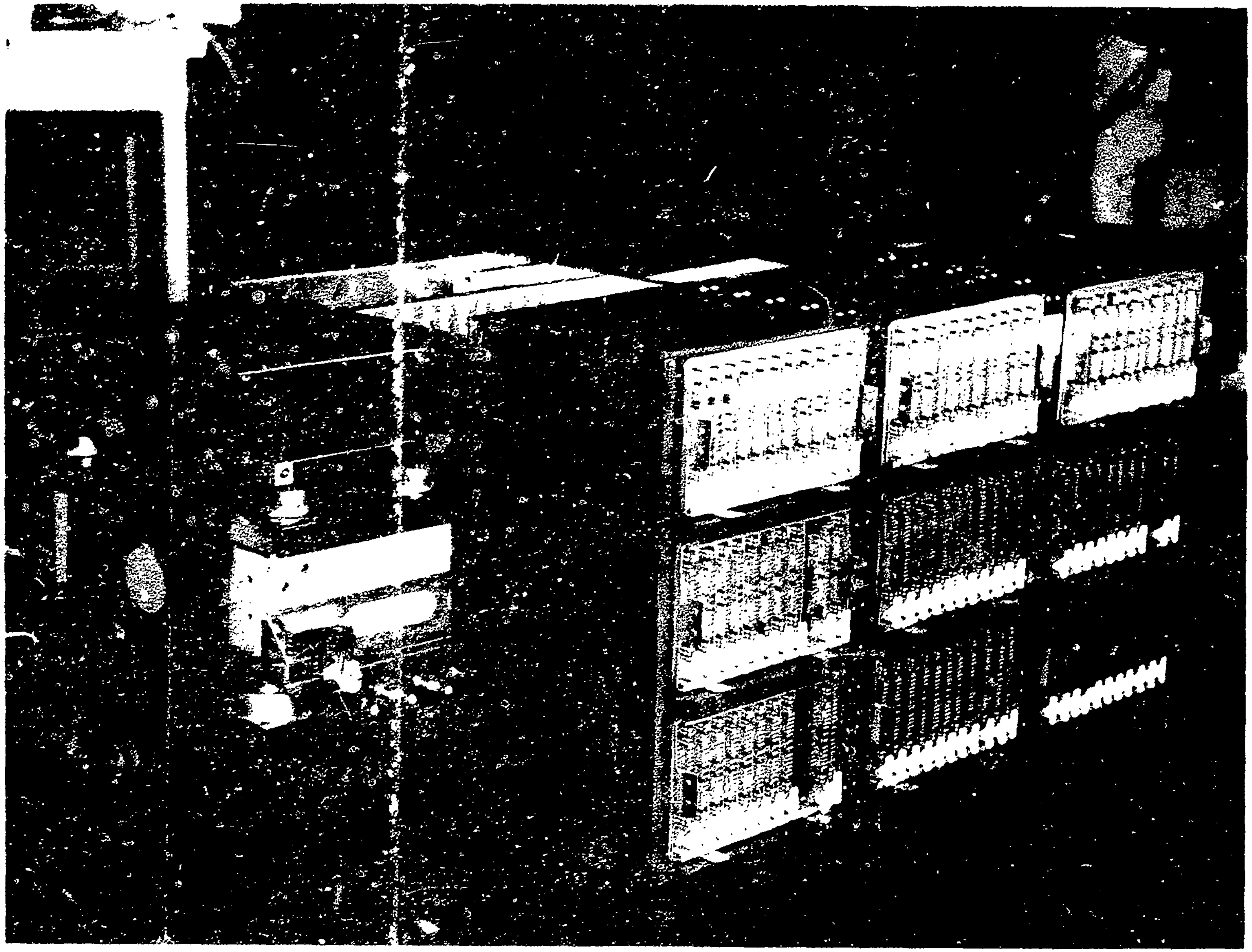


Figure A-17. AH-1S instrumentation package (right side).

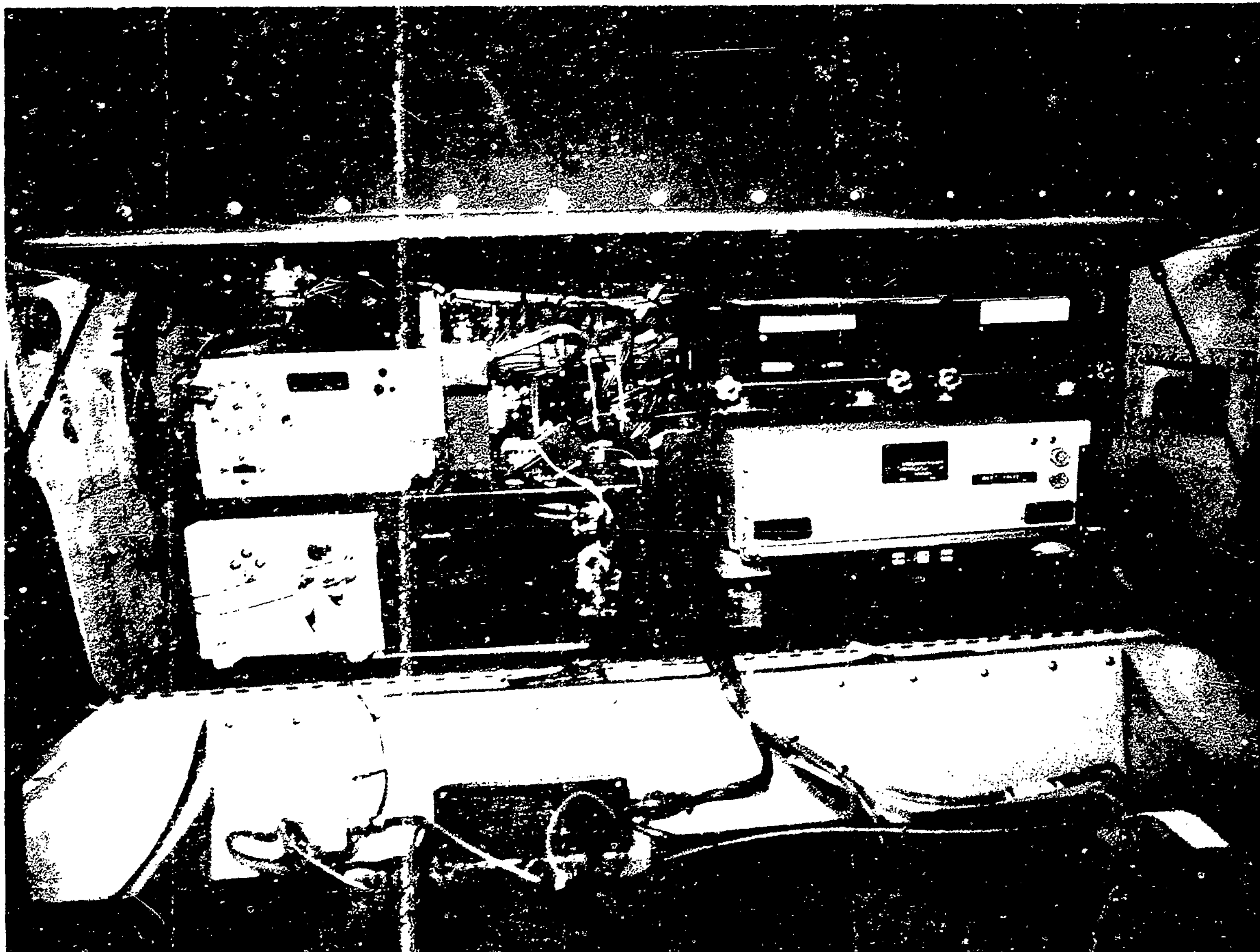


Figure A-18. AH-1S instrumentation package in ammo bay (left side).

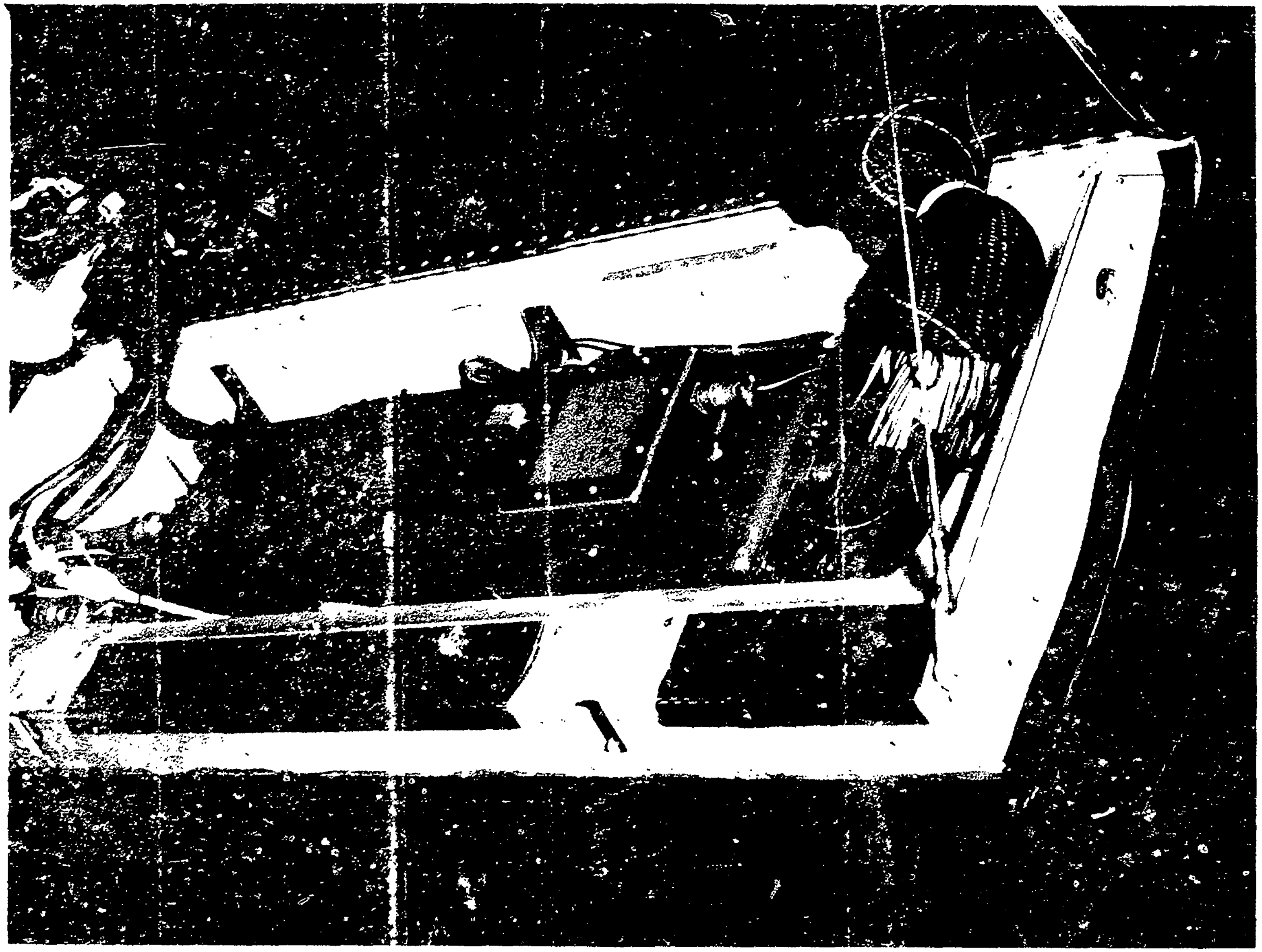


Figure A-19. AH-1S instrumentation in modified ammo bay door (right side).

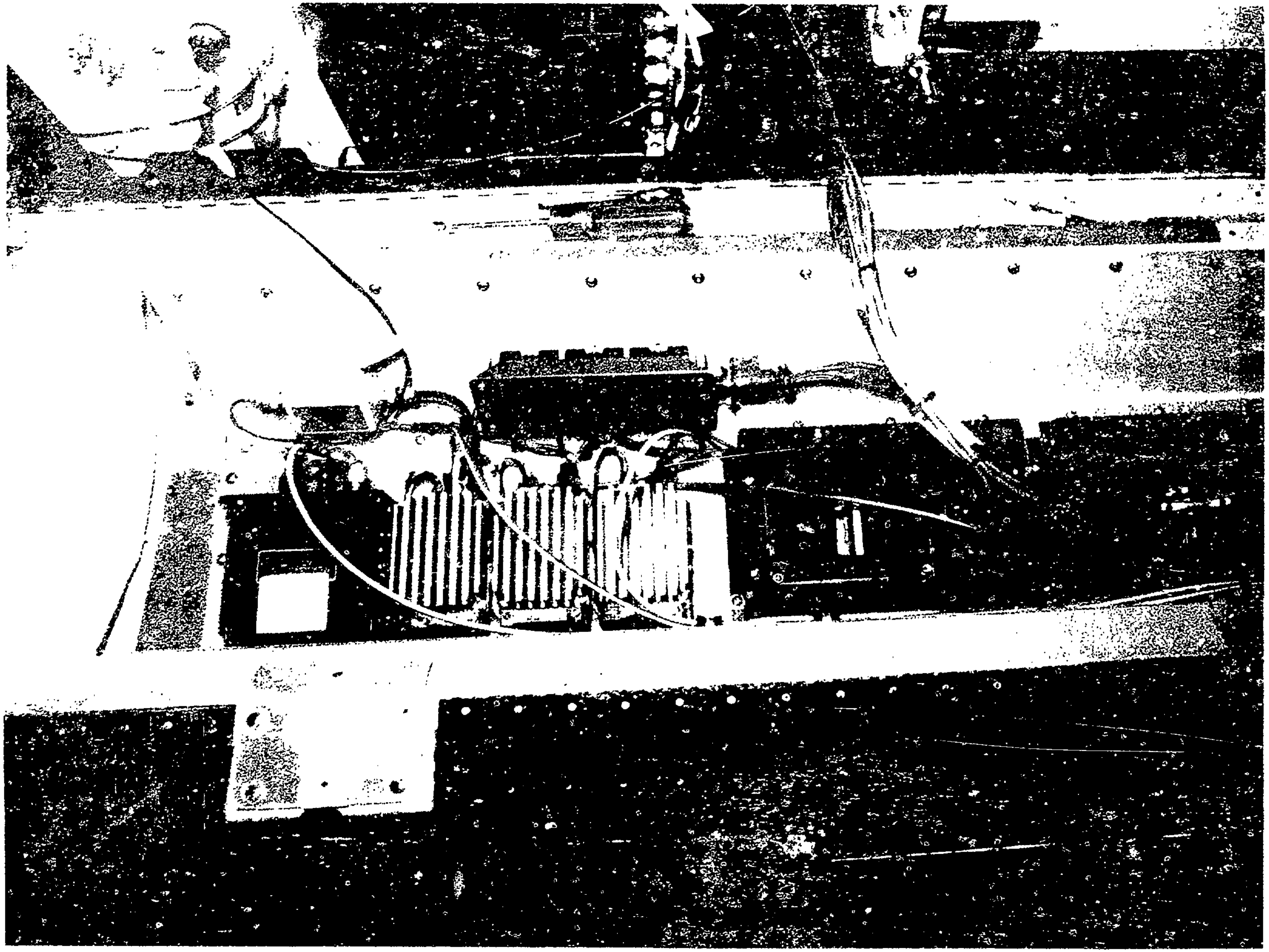


Figure 20. AH-1S instrumentation in modified ammo bay door (left side).

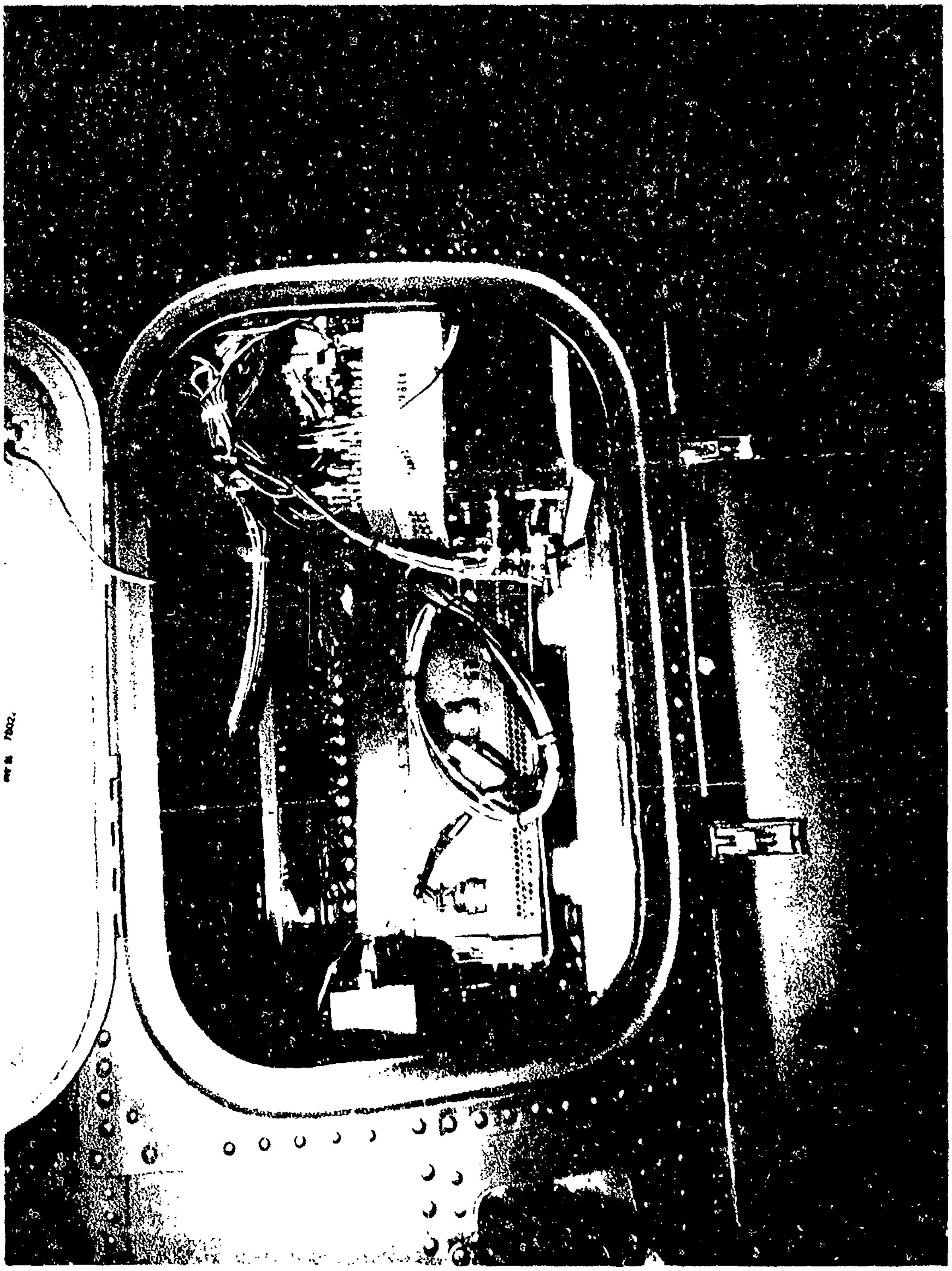


Figure A-21. AH-64A instrumentation.

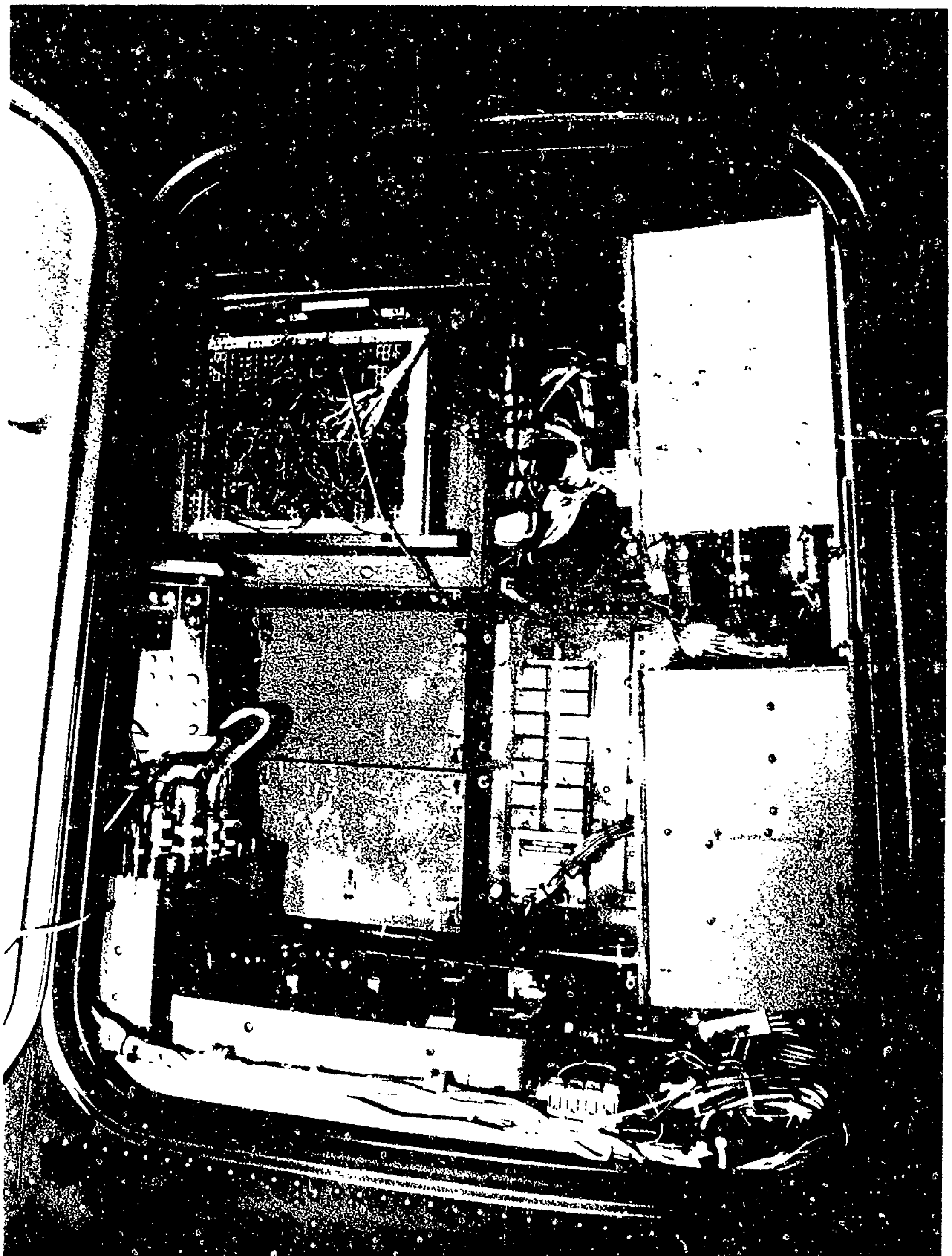


Figure A-21. AH-64A instrumentation. (Continued)

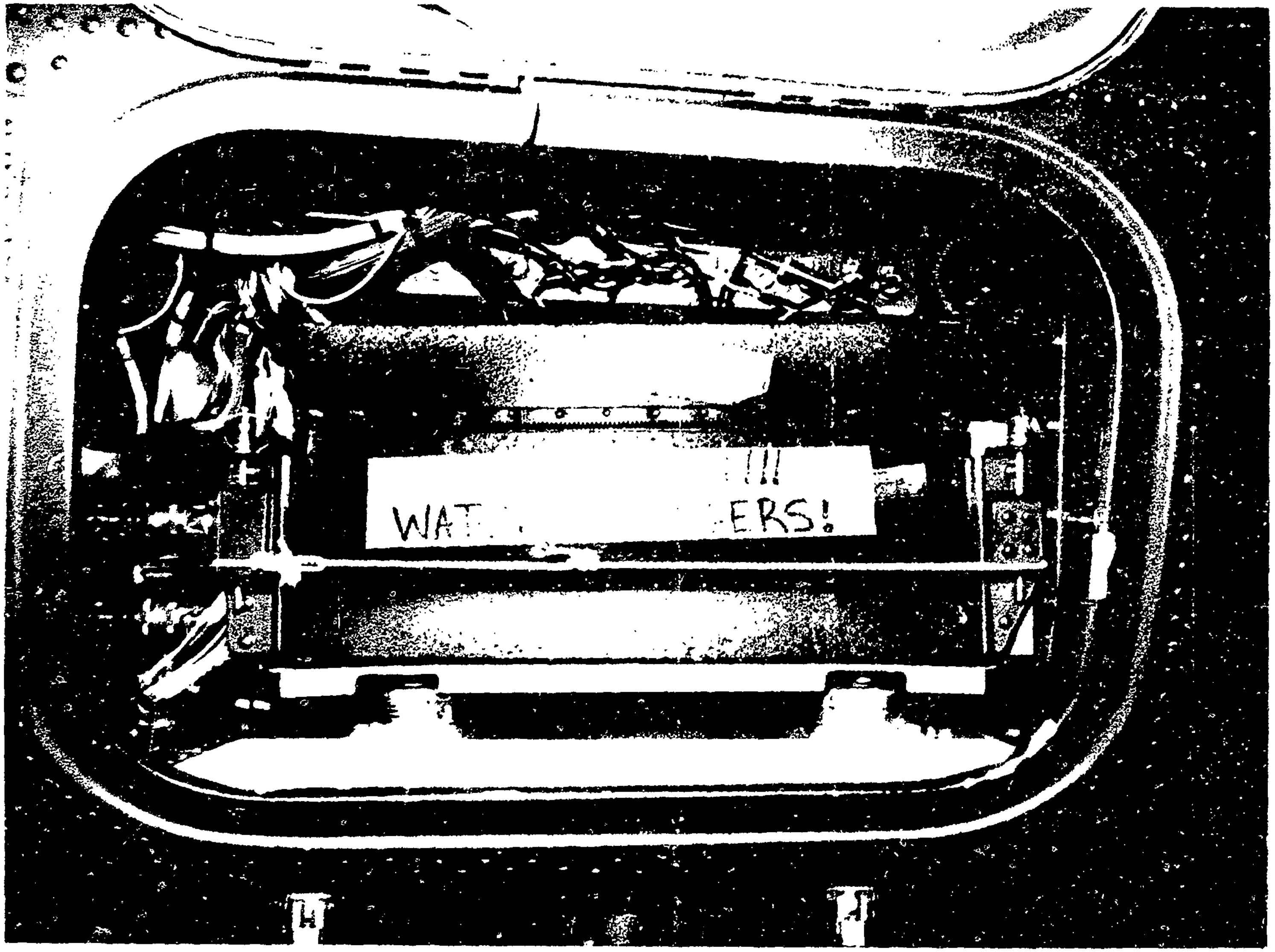


Figure A-21. AH-64A instrumentation. (Continued)

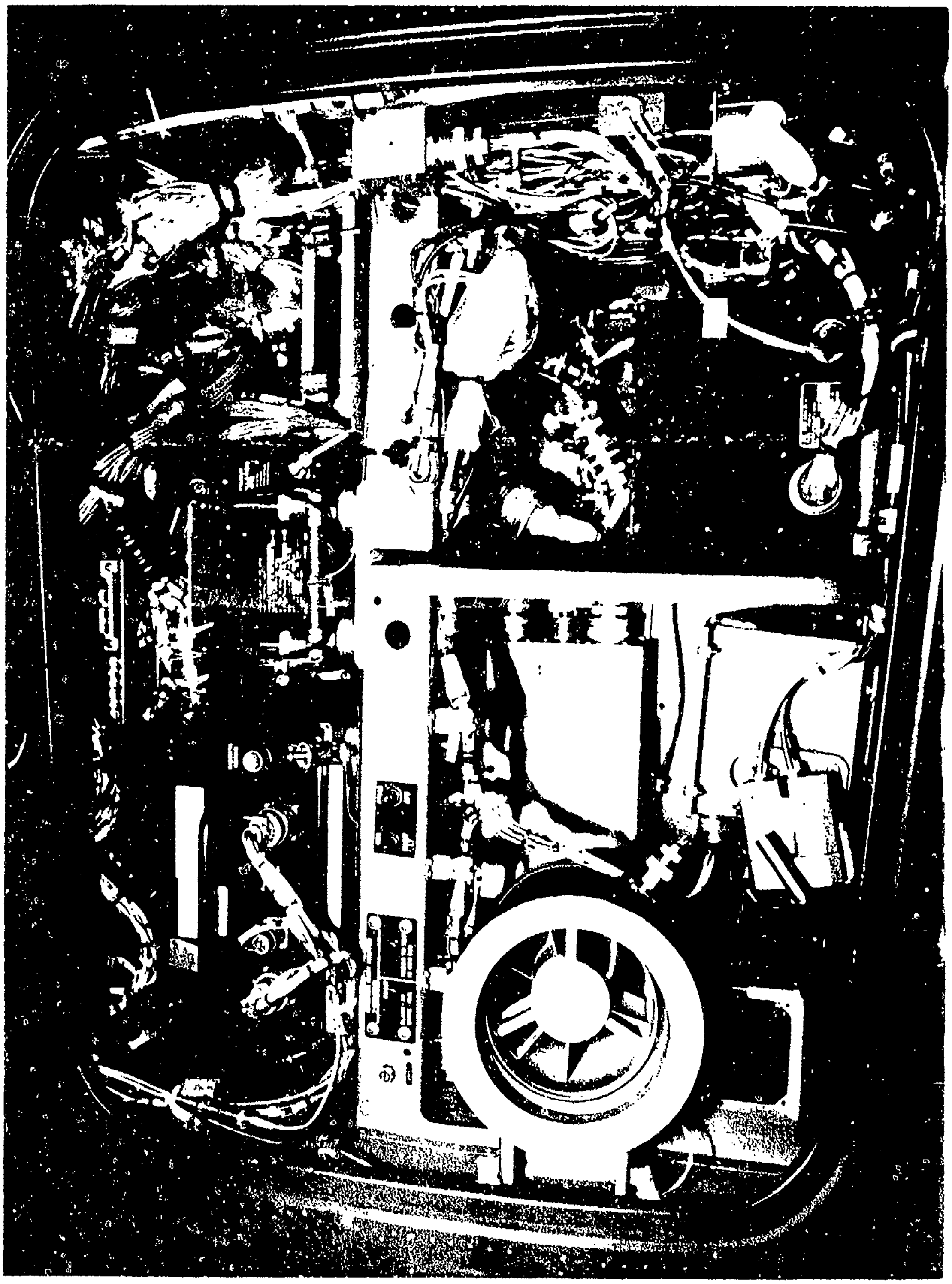


Figure A-21. AH-64A instrumentation. (Continued)

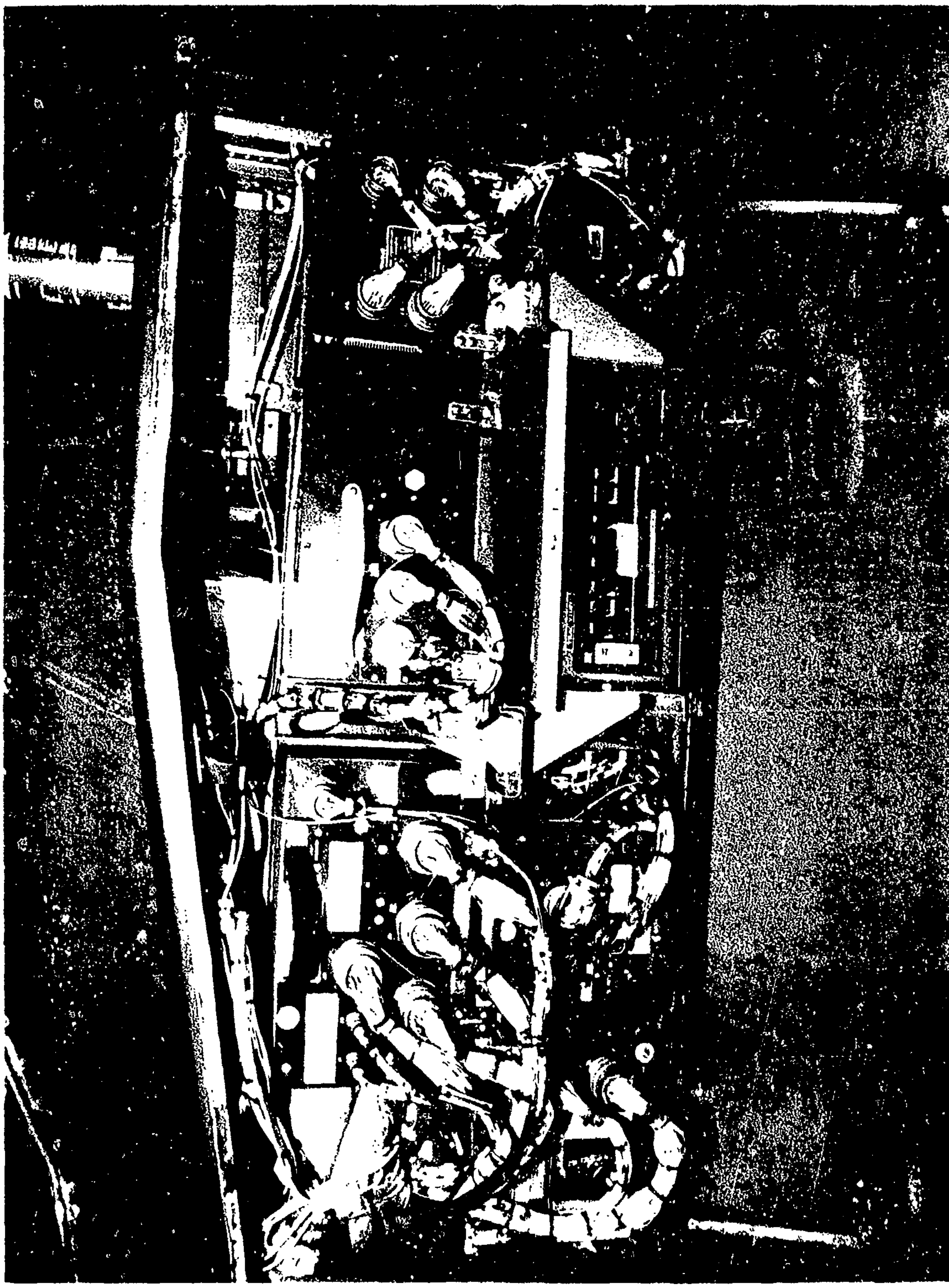


Figure A-21. AH-64A instrumentation. (Concluded)

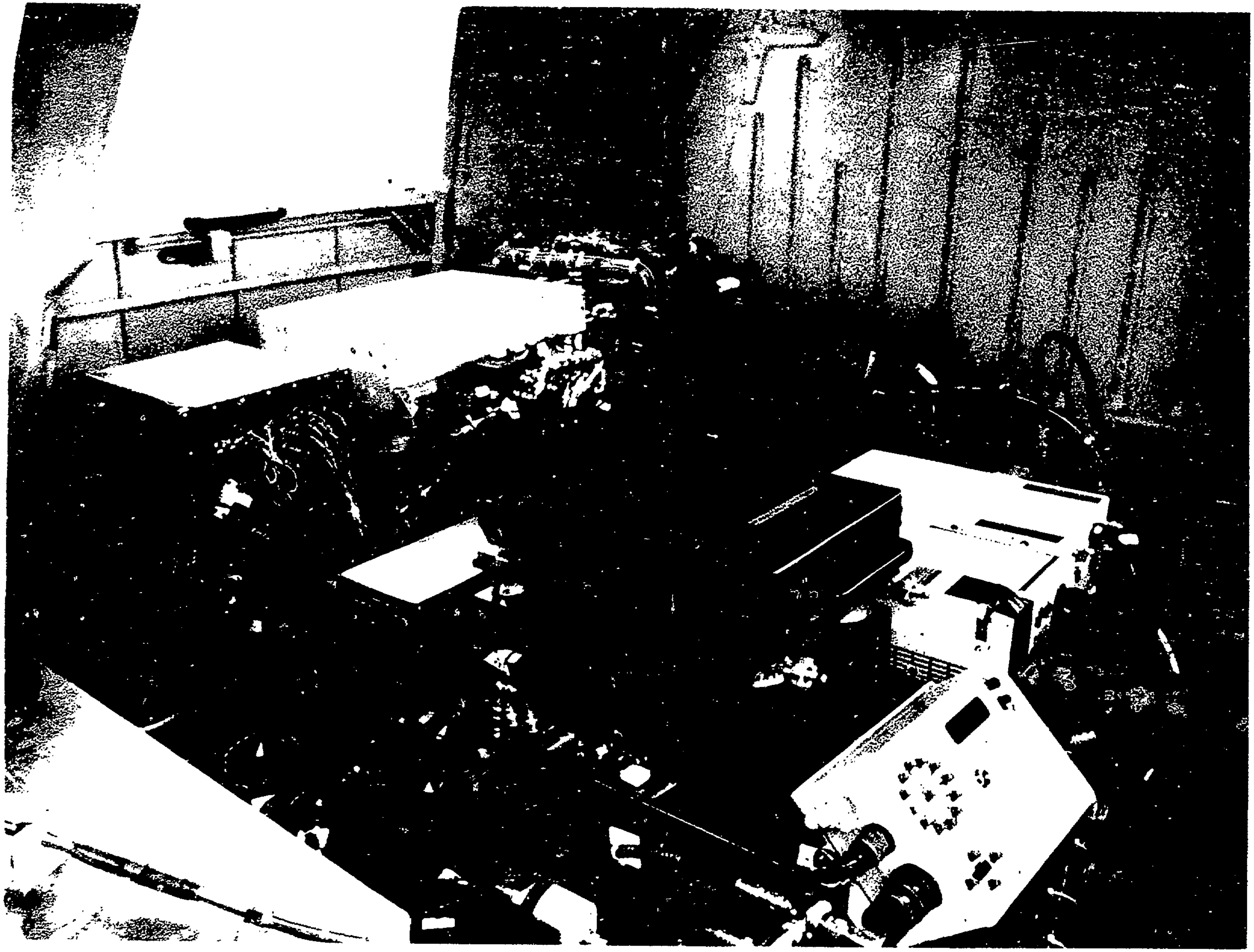


Figure A-22. SA-365N-1 instrumentation package.

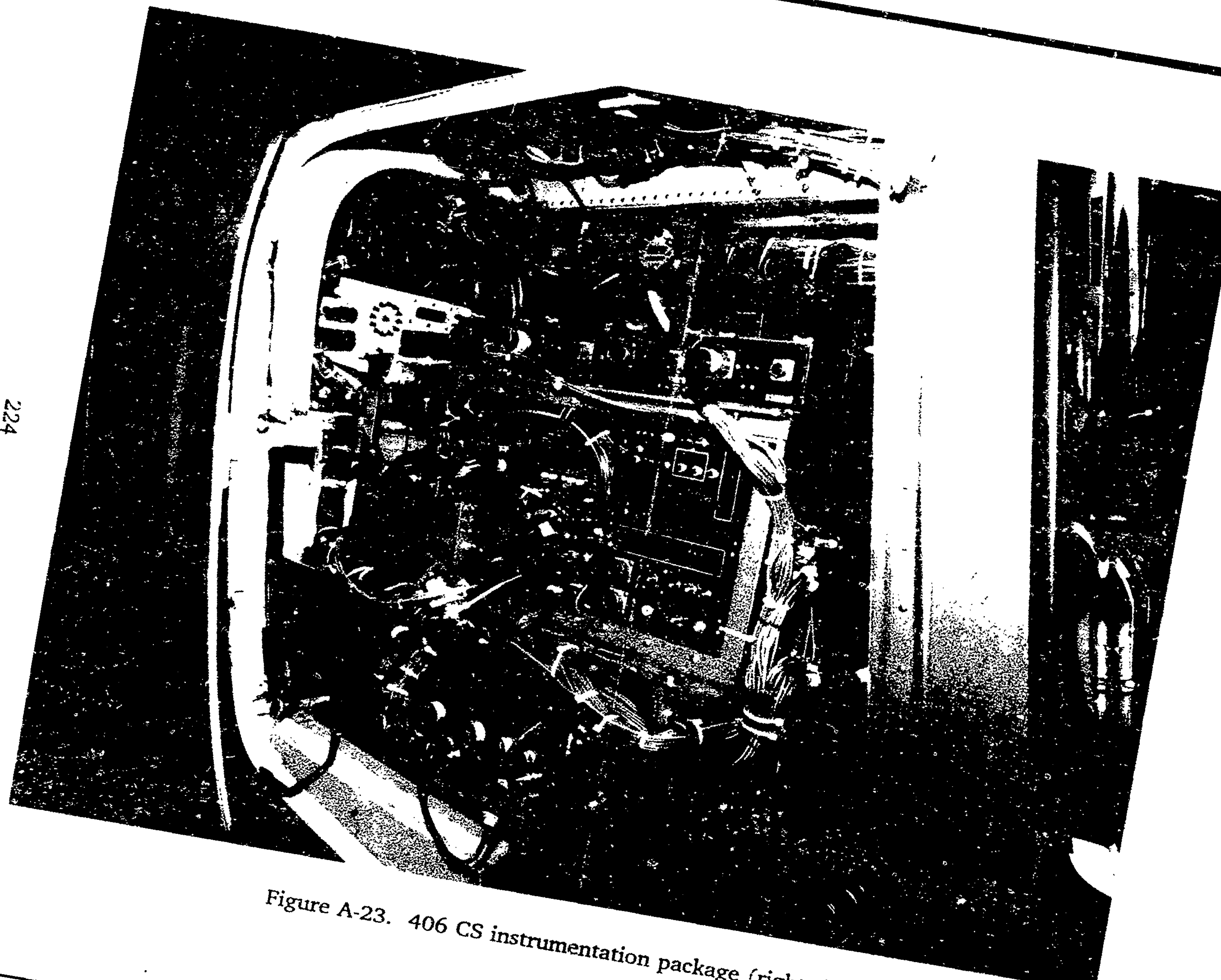


Figure A-23. 406 CS instrumentation package (right side).

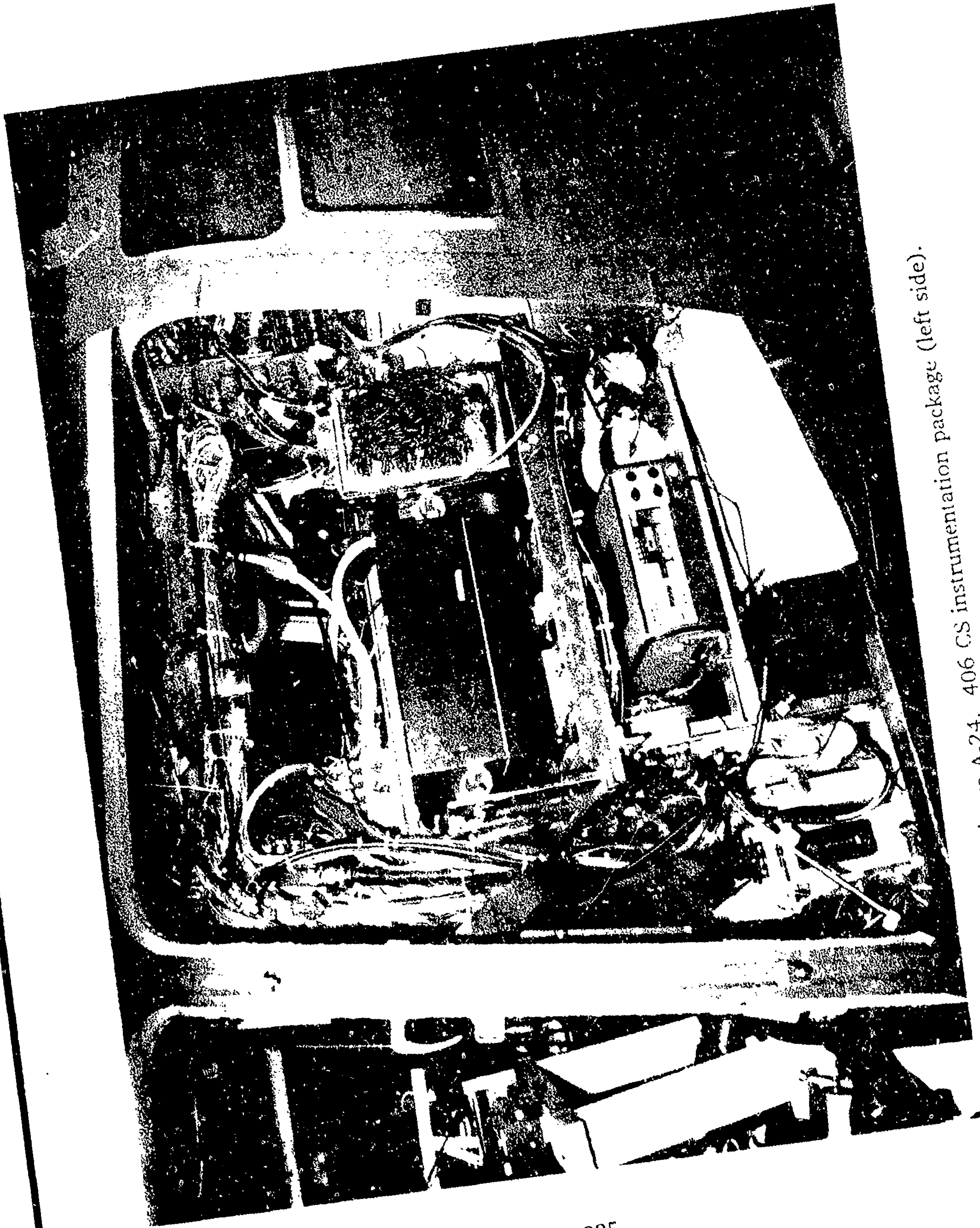


Figure A-24. 406 CS instrumentation package (left side).

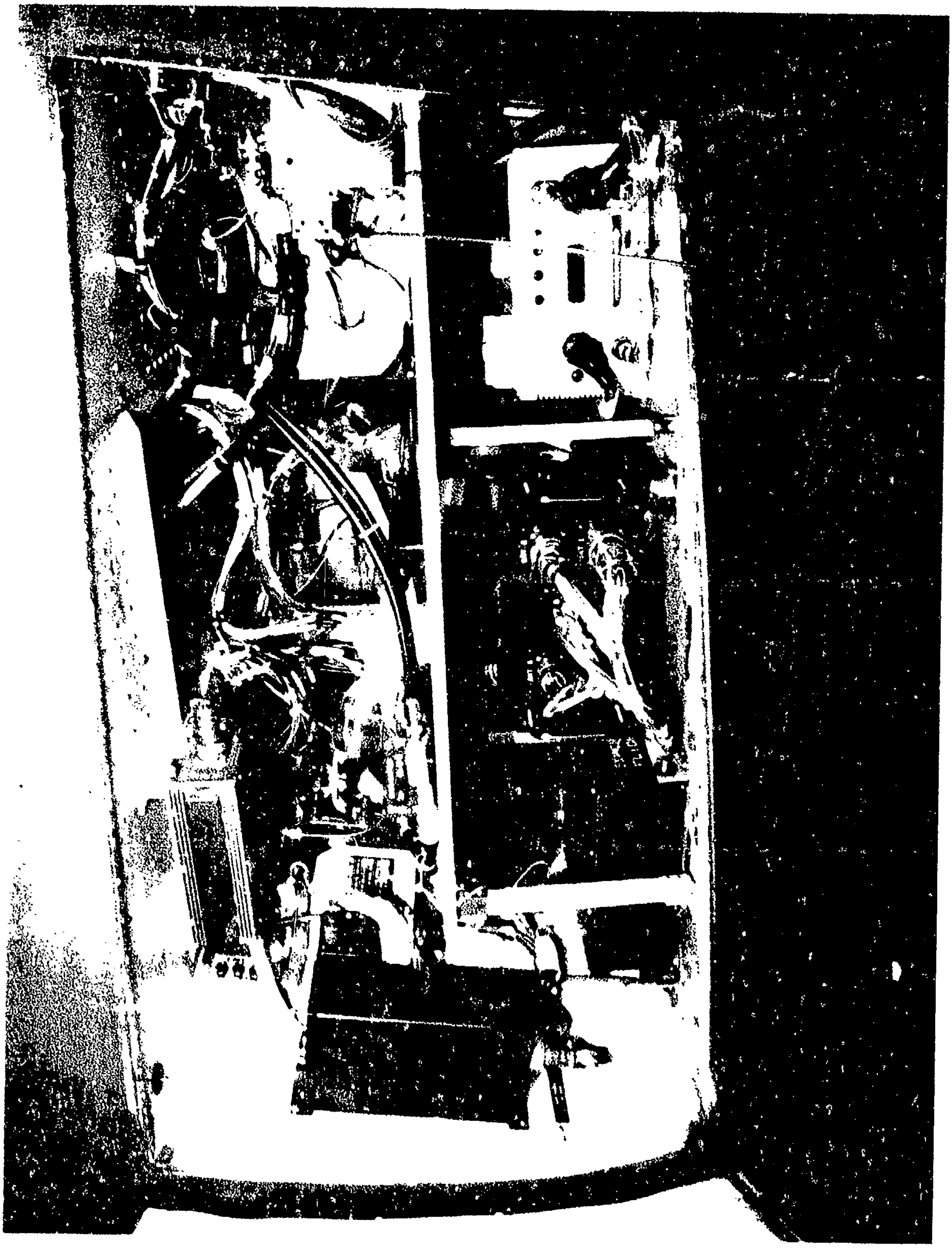


Figure A-25. 406 CS instrumentation (aft).

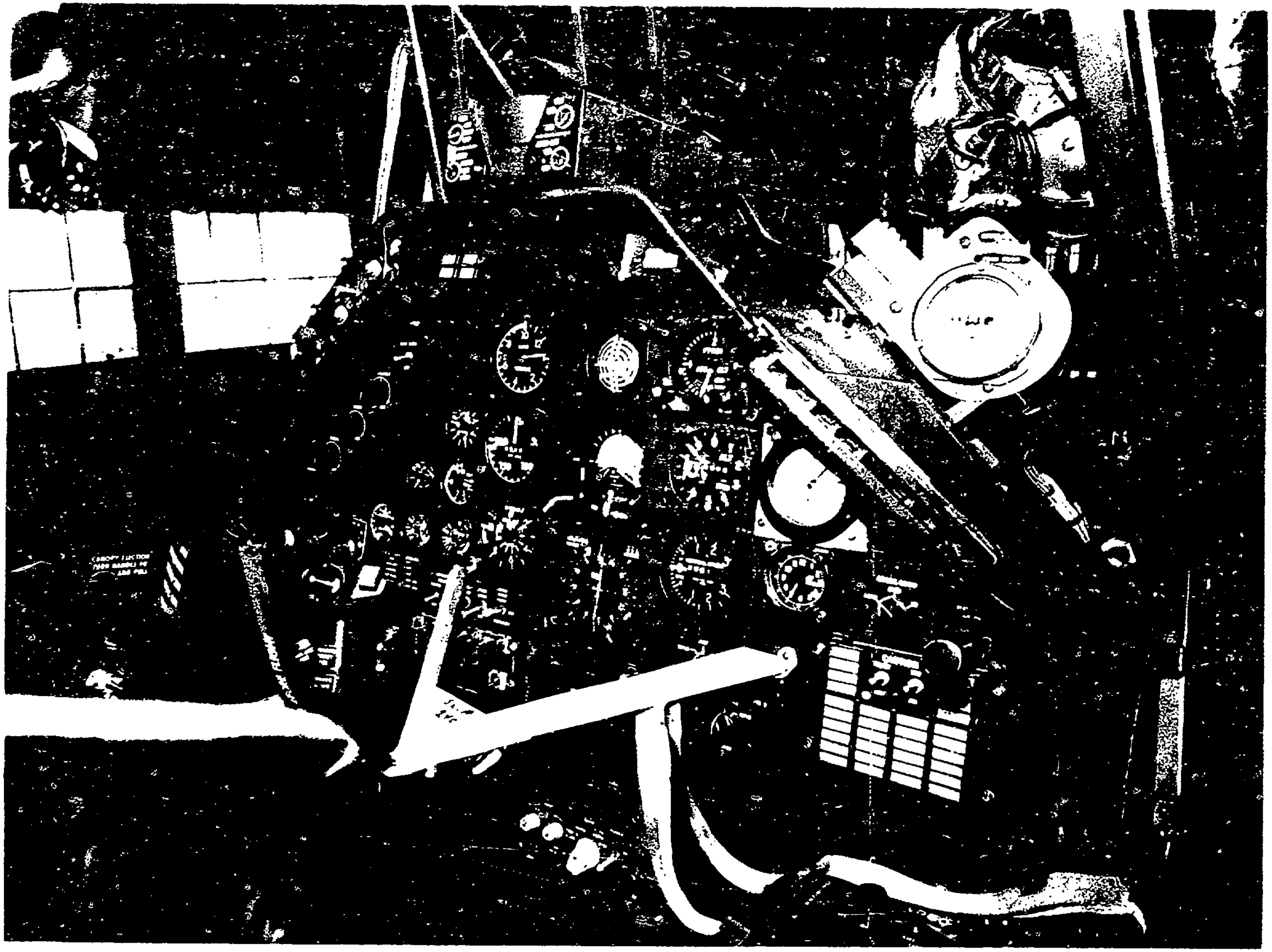


Figure A-26. AH-1S pilot instrument panel.

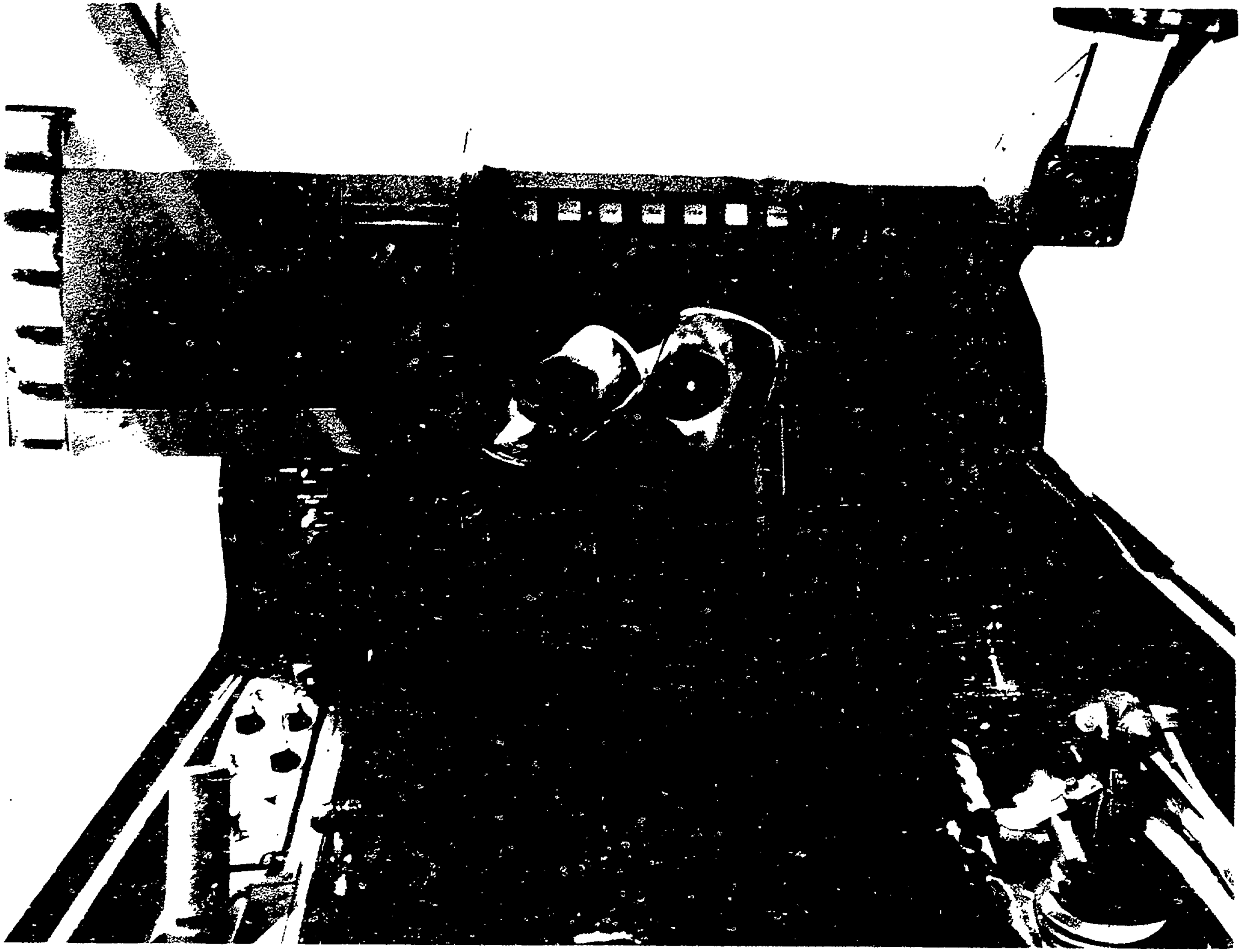


Figure A-27. AH-1S copilot/gunner instrument panel.

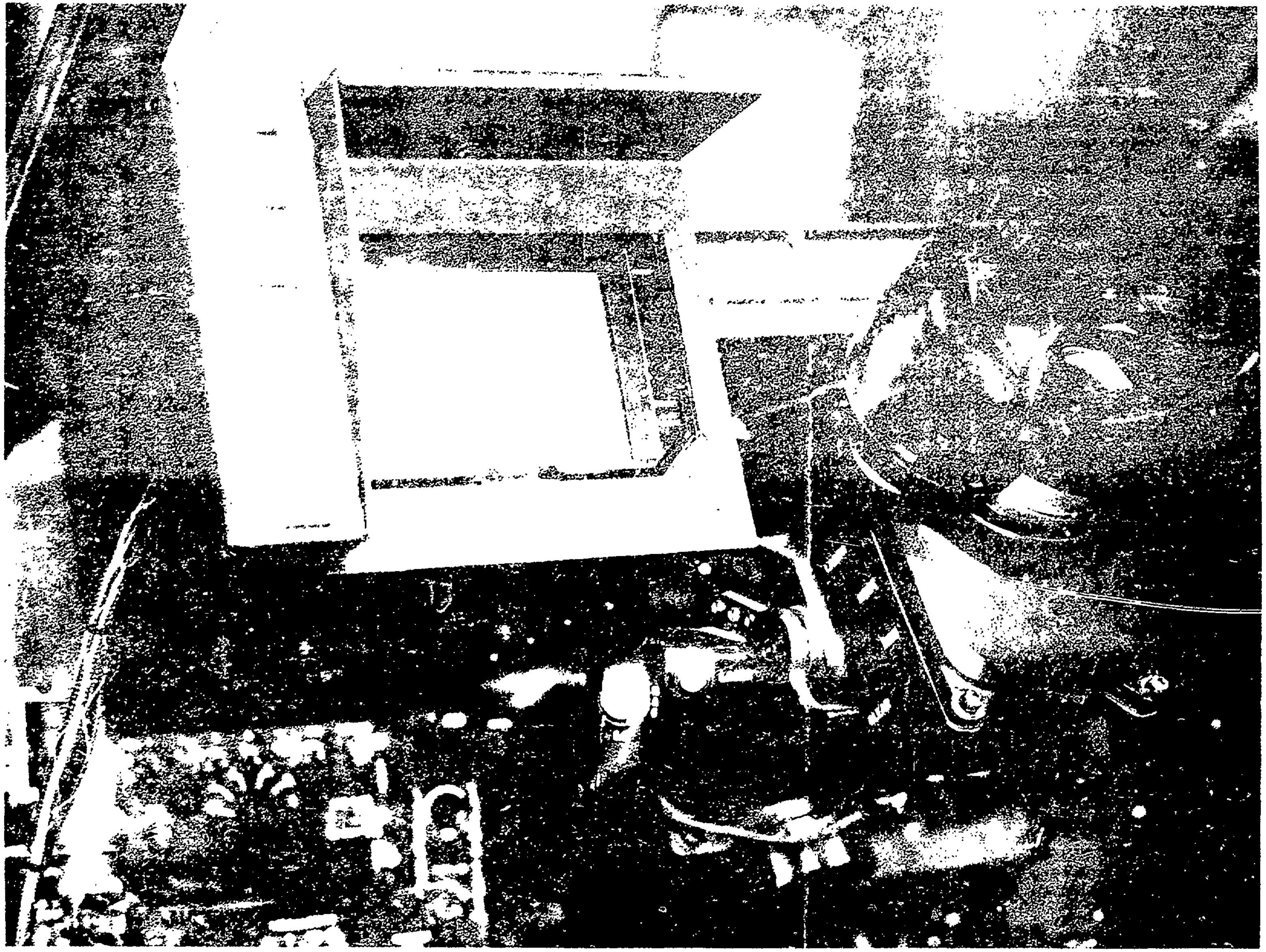


Figure A-28. AH-1S turret video monitor in copilot station.

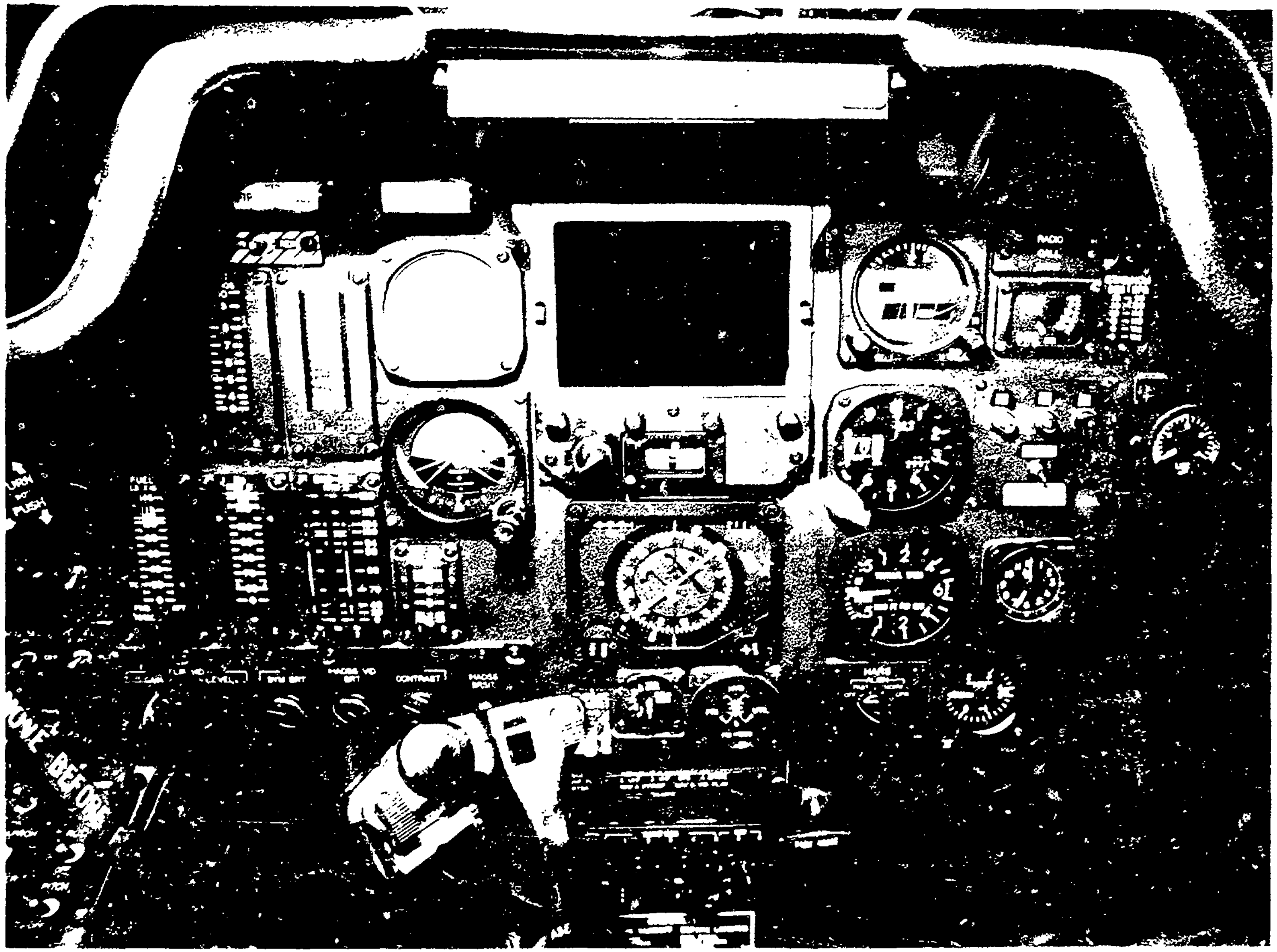


Figure A-29. AH-64A pilot instrument panel.

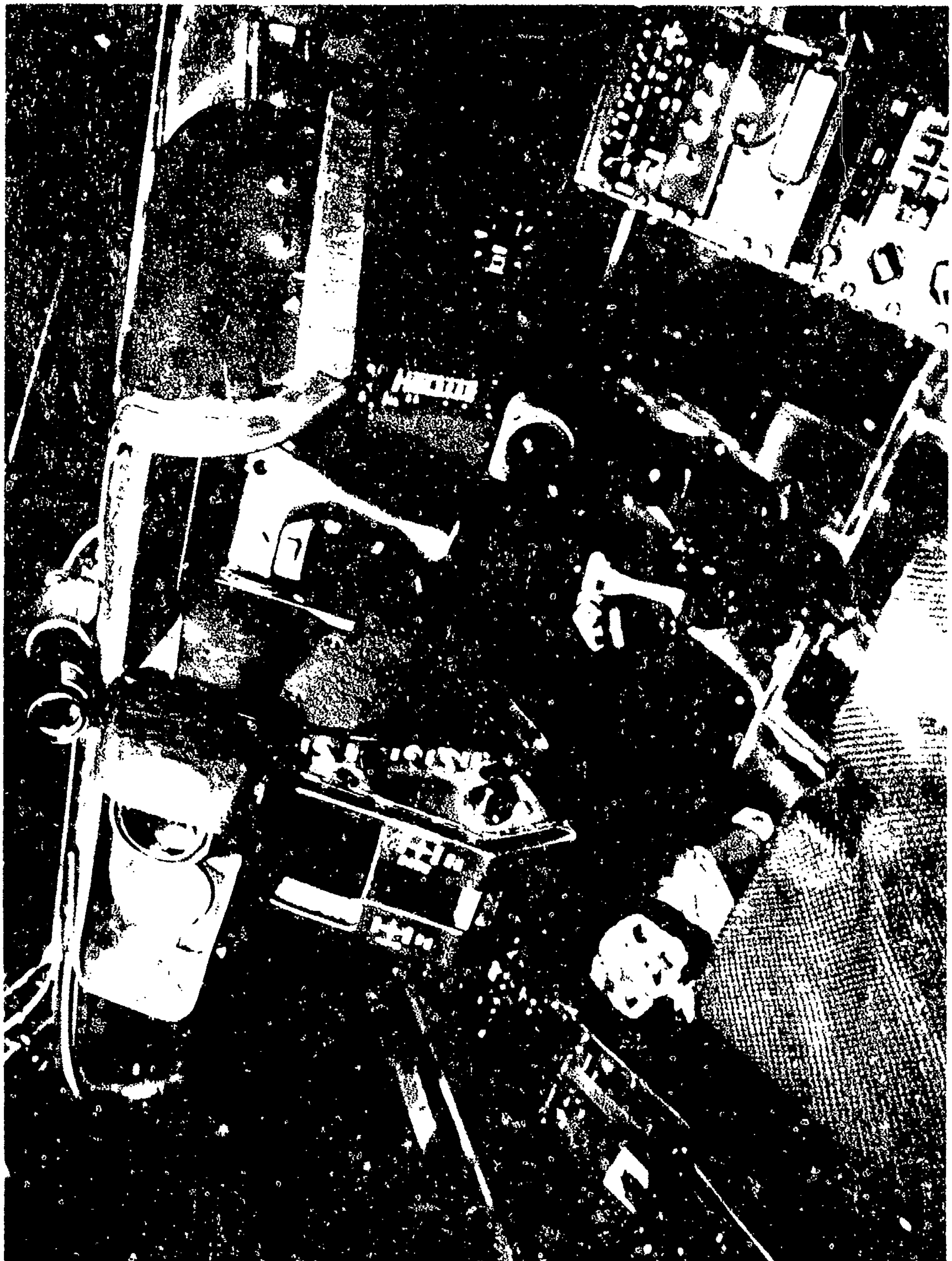


Figure A-30. AH-64A copilot/gunner instrument panel.

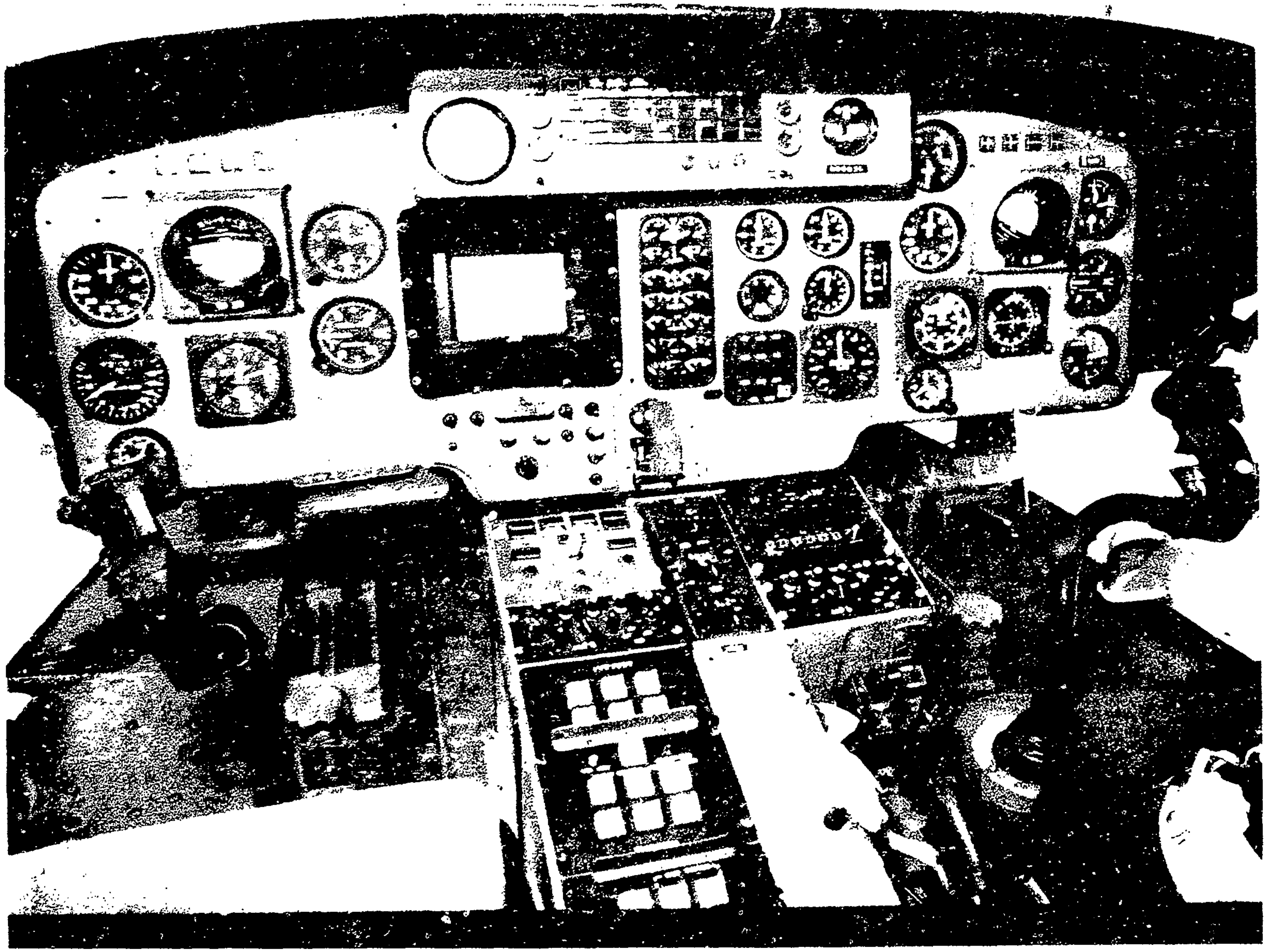


Figure A-31. SA-365N-1 pilot/copilot instrument panel.

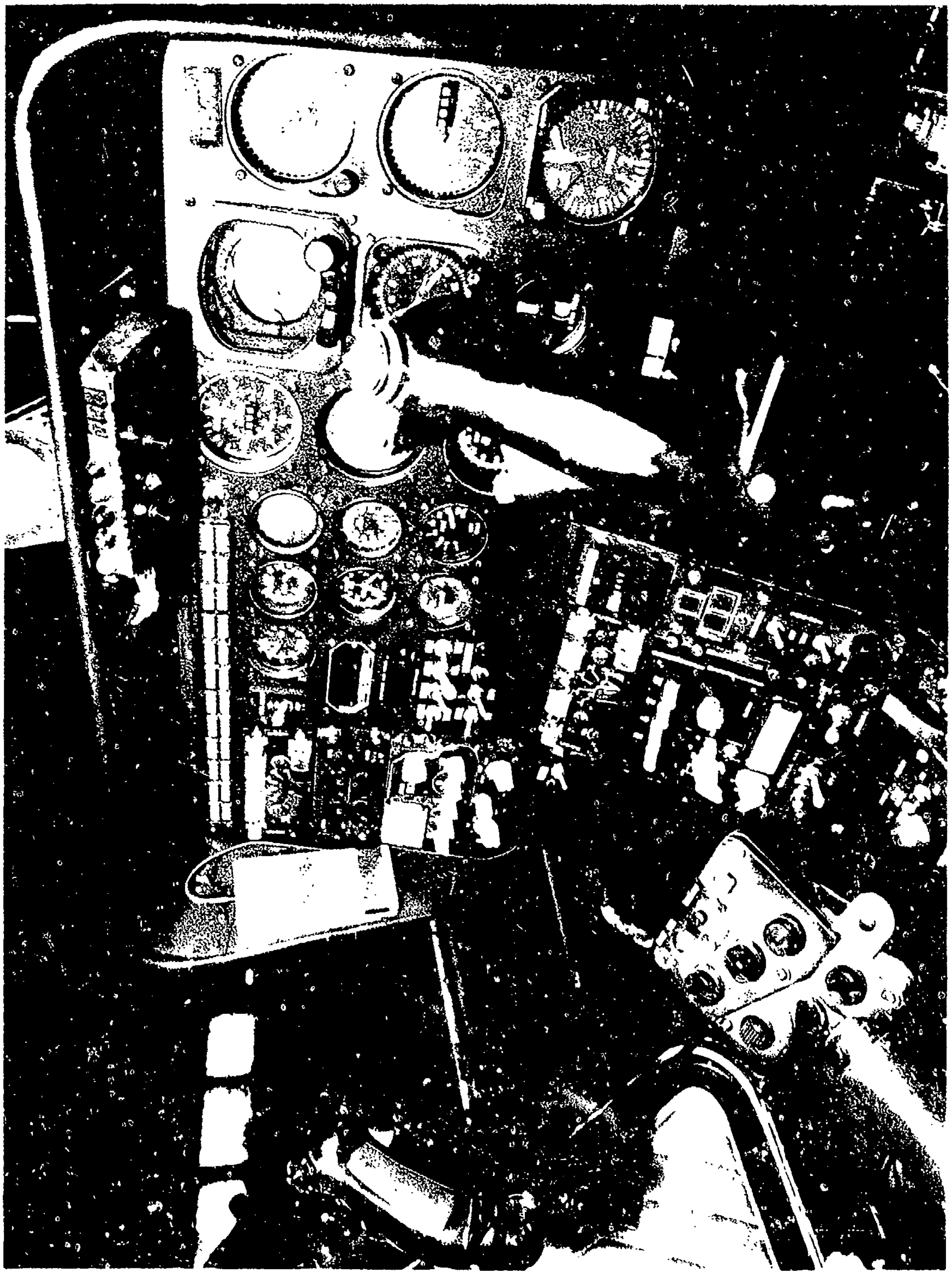


Figure A-32. 406 CS pilot/copilot instrument panel.

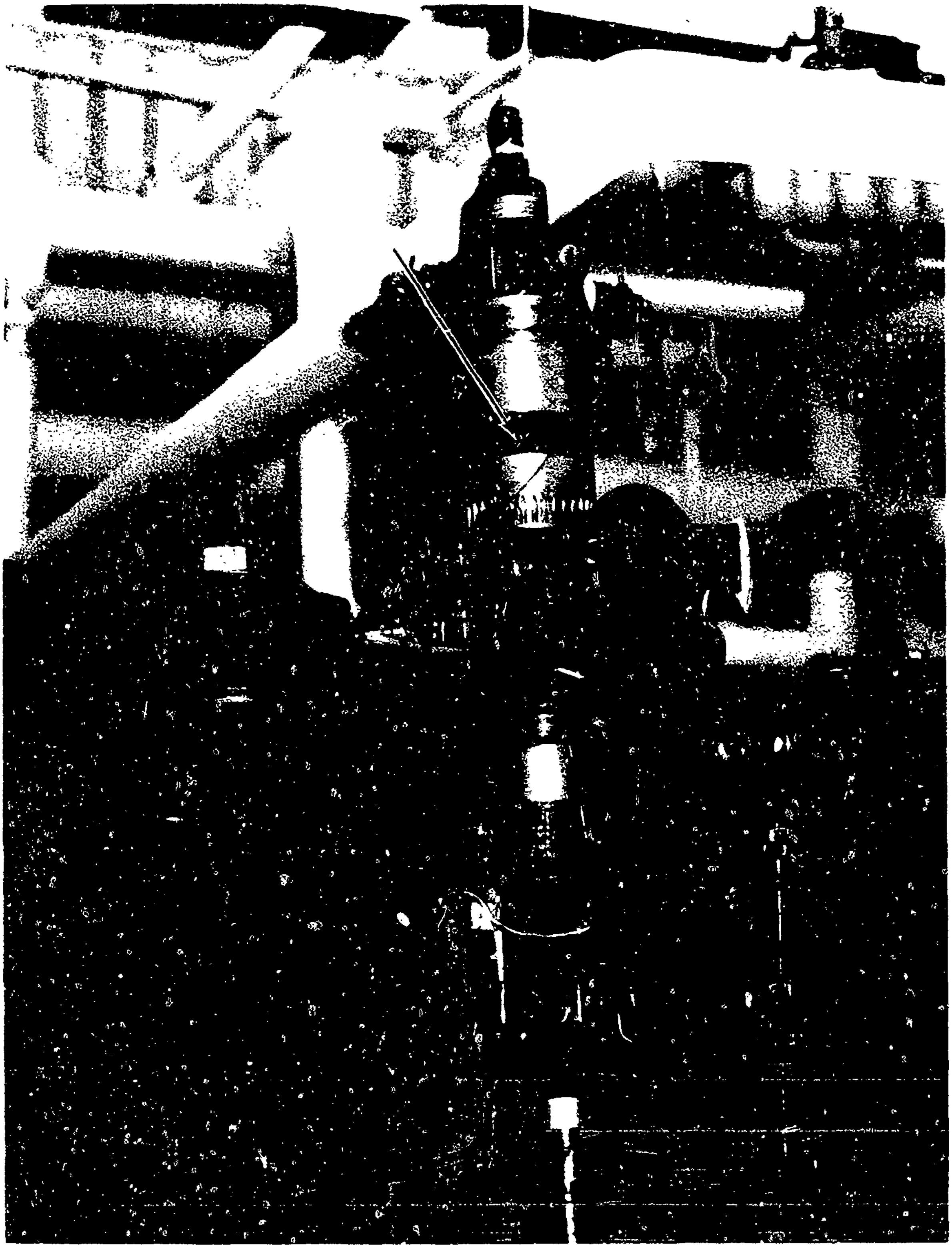


Figure A-33. AH-1S main rotor slip ring assembly.

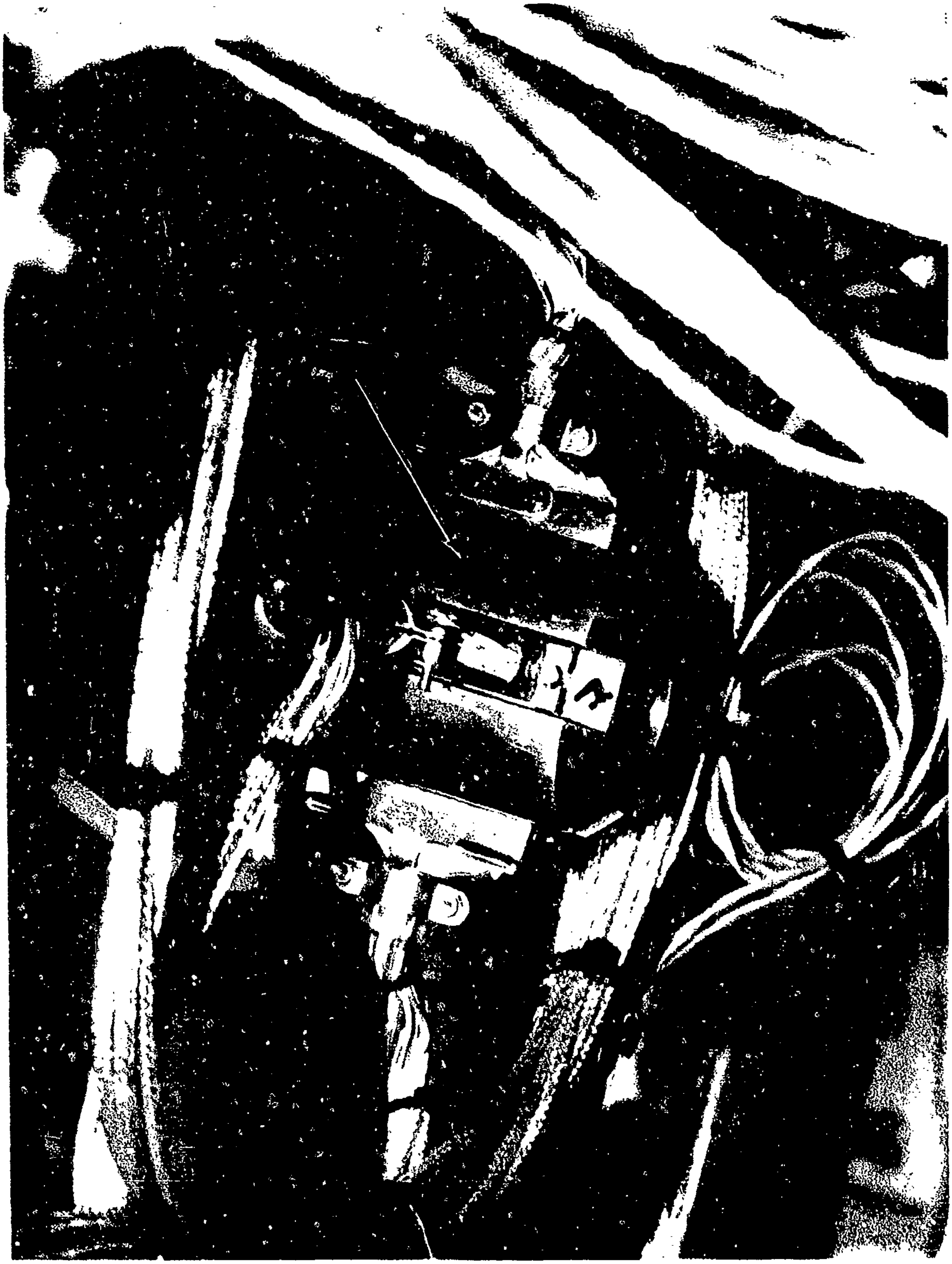


Figure A-34. SA-365N-1 main rotor slip ring assembly (at base of transmission).

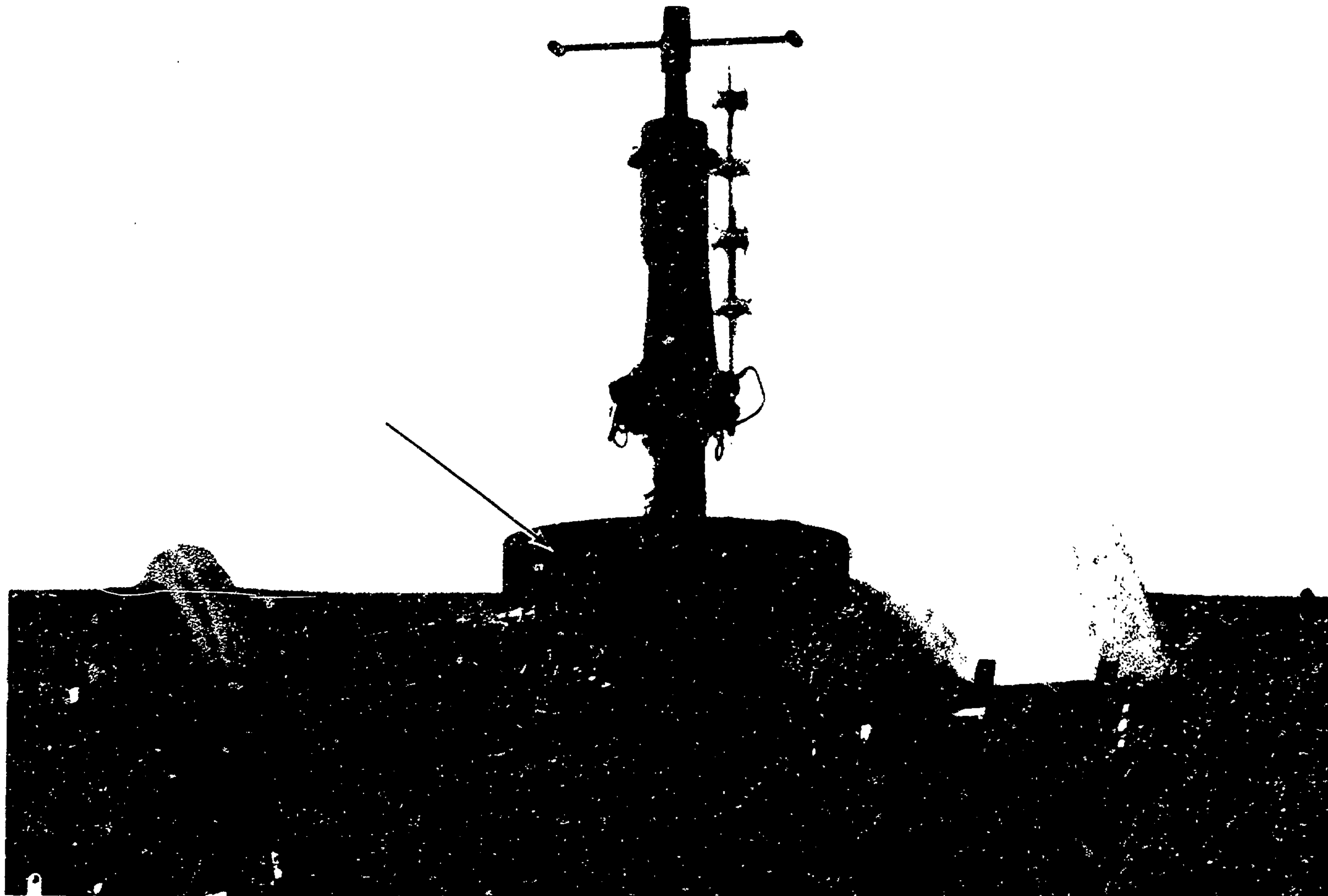


Figure A-35. AH-64A main rotor slip ring assembly.

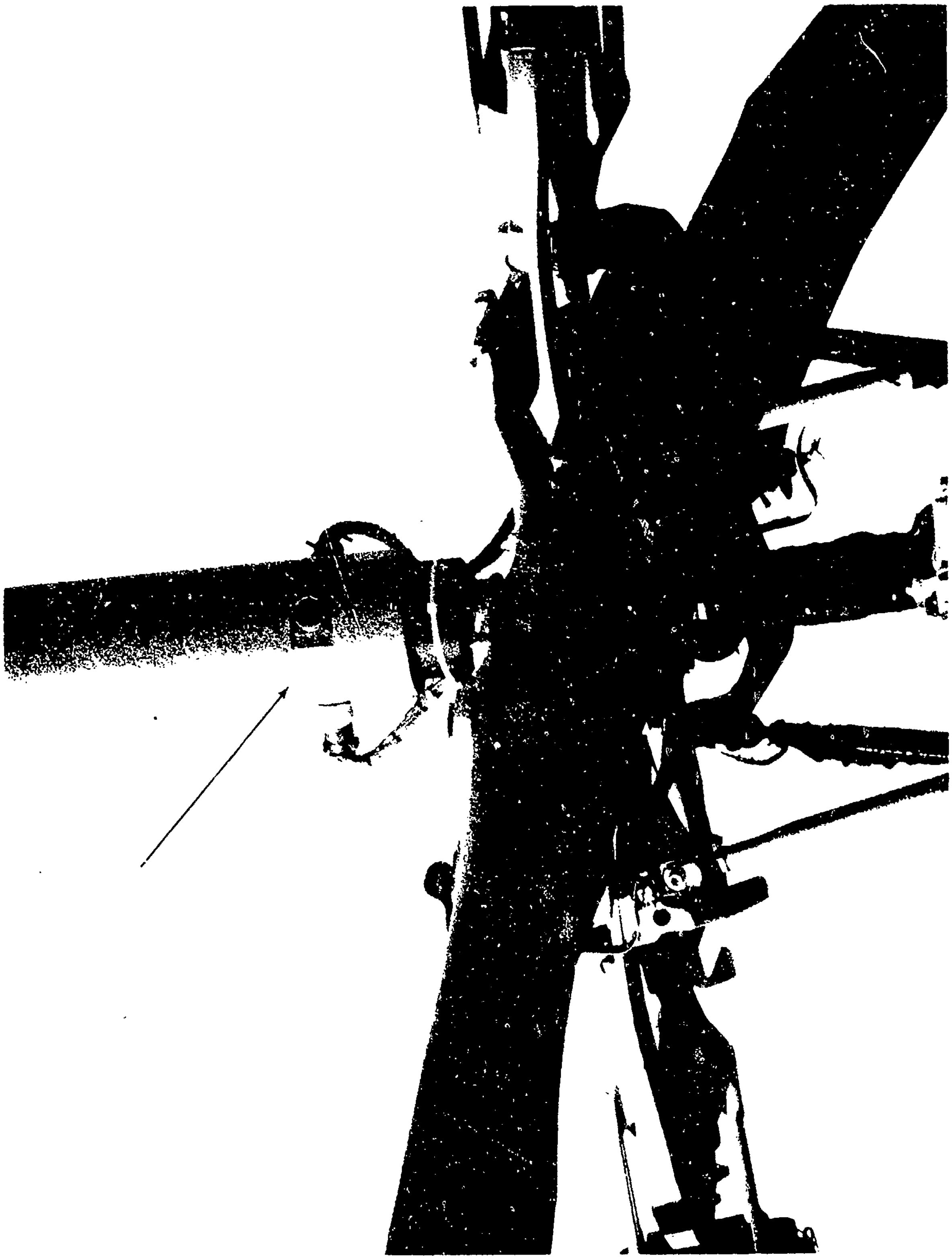


Figure A-36. 406 CS main rotor slip ring assembly.

Figure A-37. AH-1S modified ammo bay door.

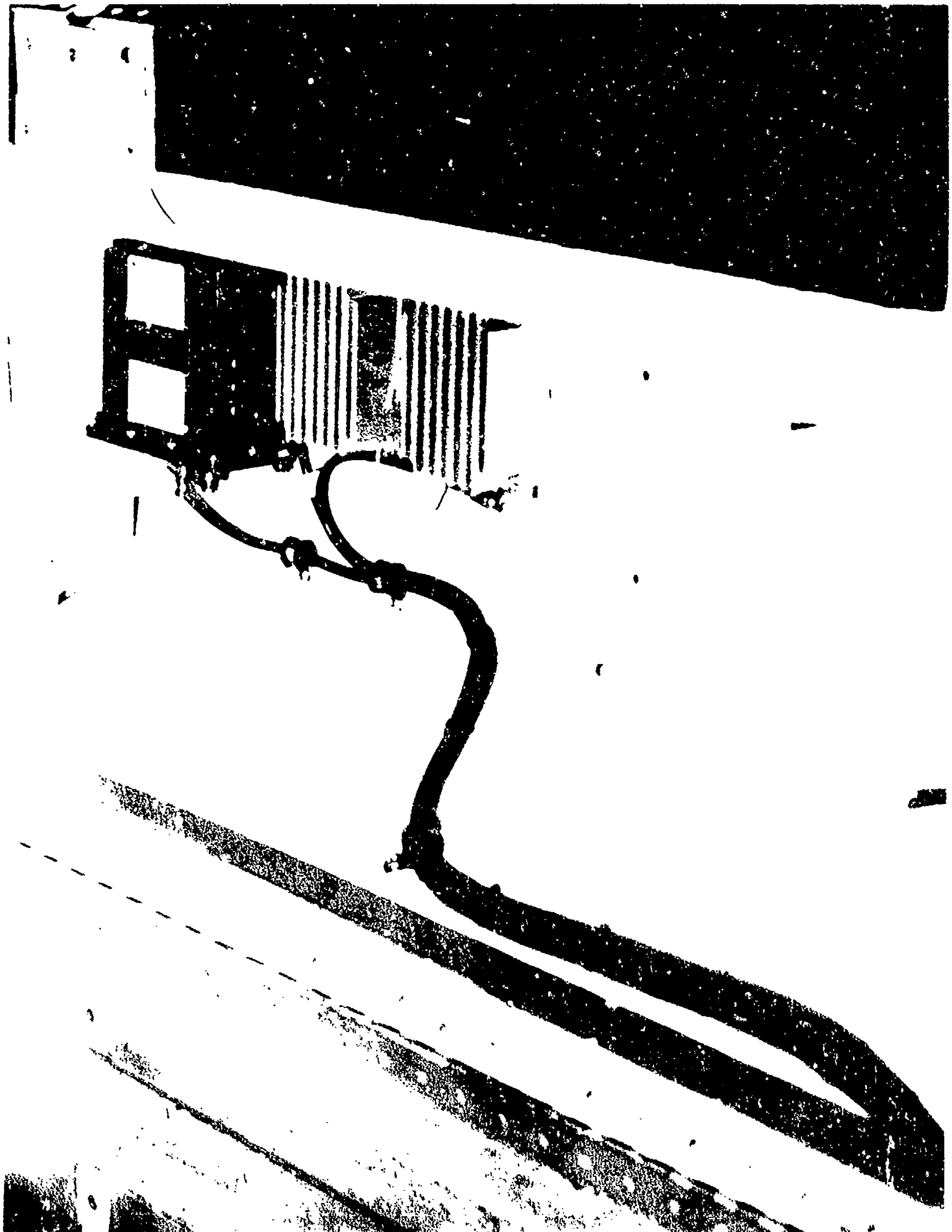


Figure A-38. AH-1S modified ammo bay door (interior cavity).

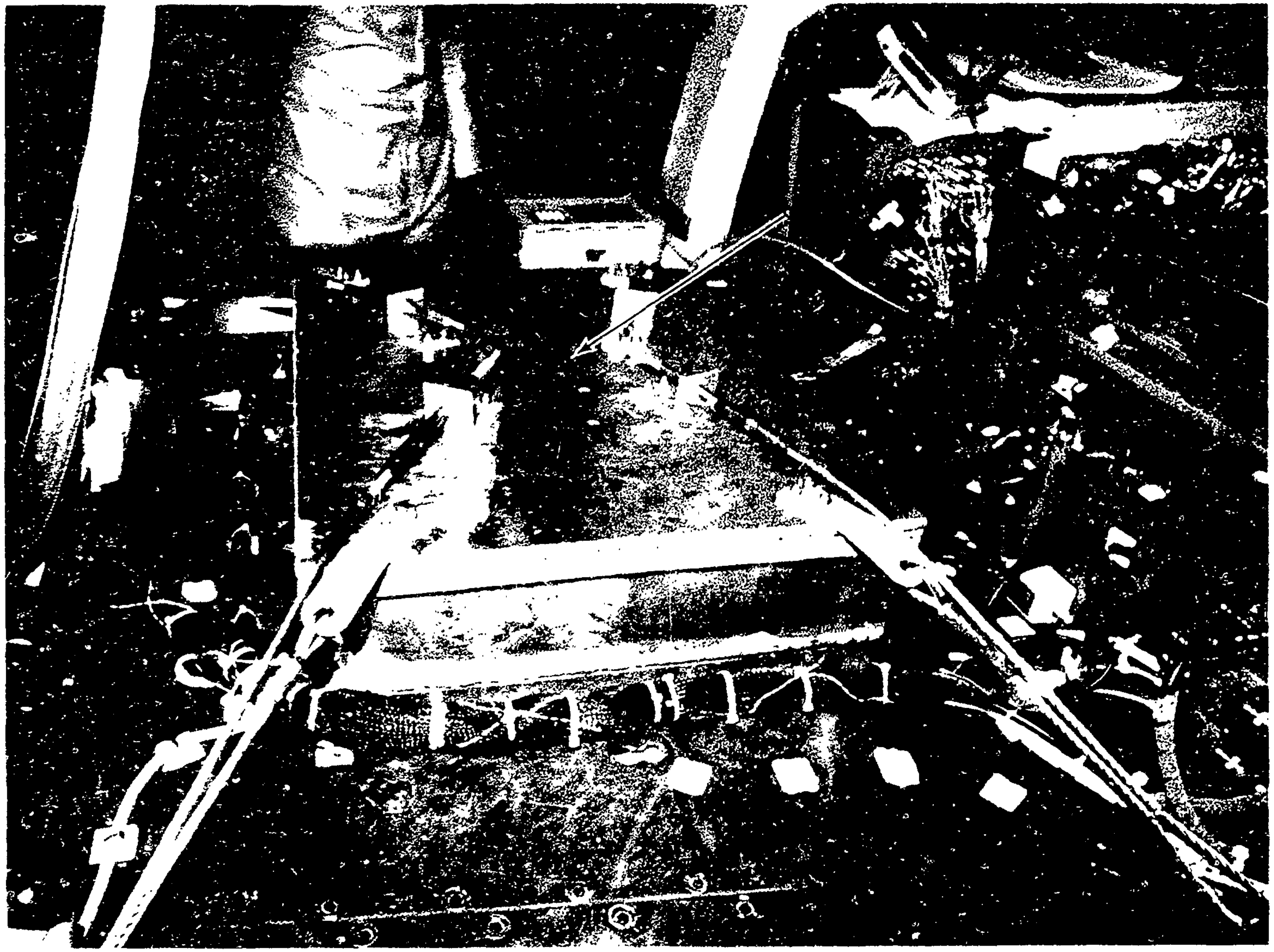


Figure A-39. SA-365N-1 ballast container (forward cabin floor).

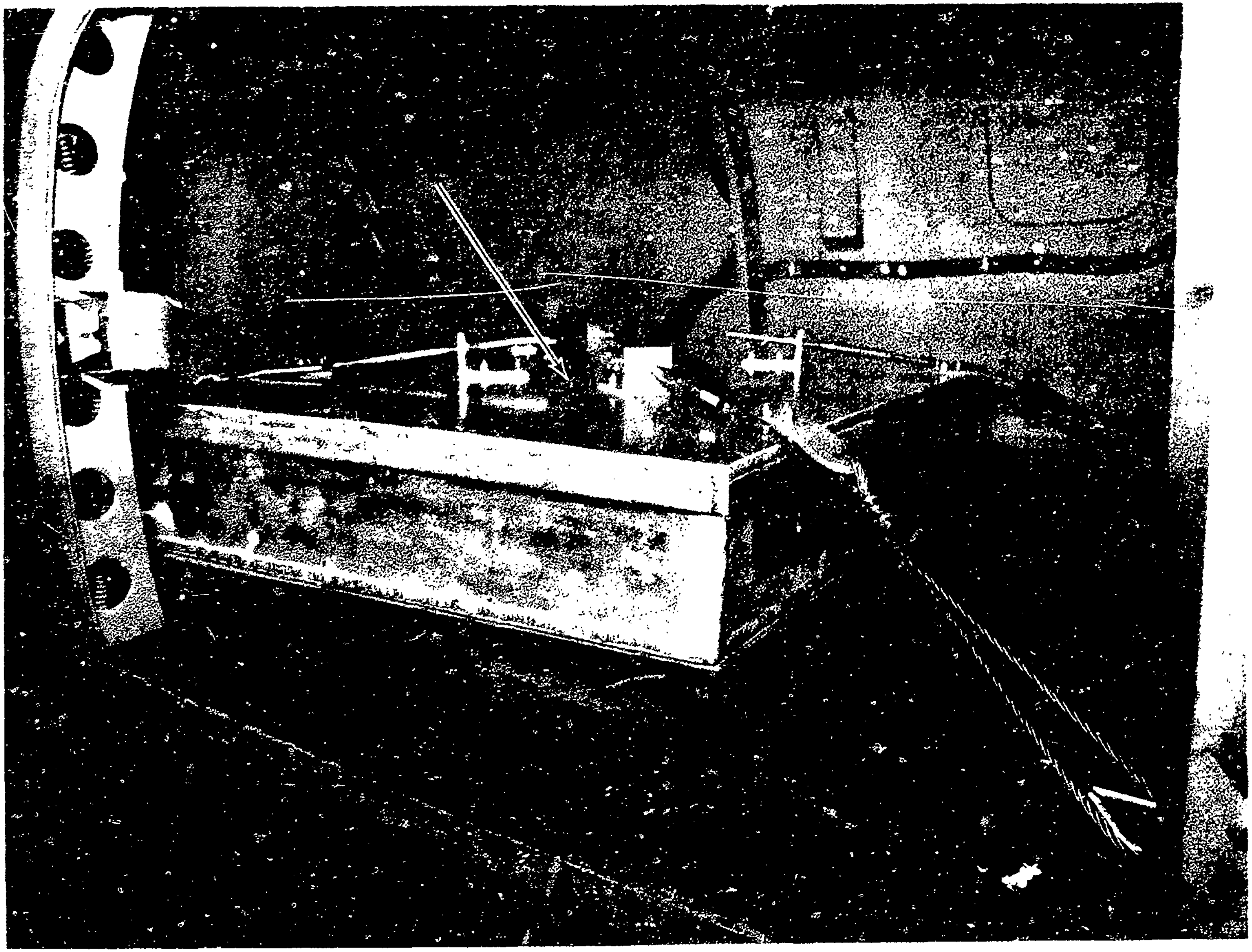


Figure A-40. SA-365N-1 ballast container (aft cargo floor).

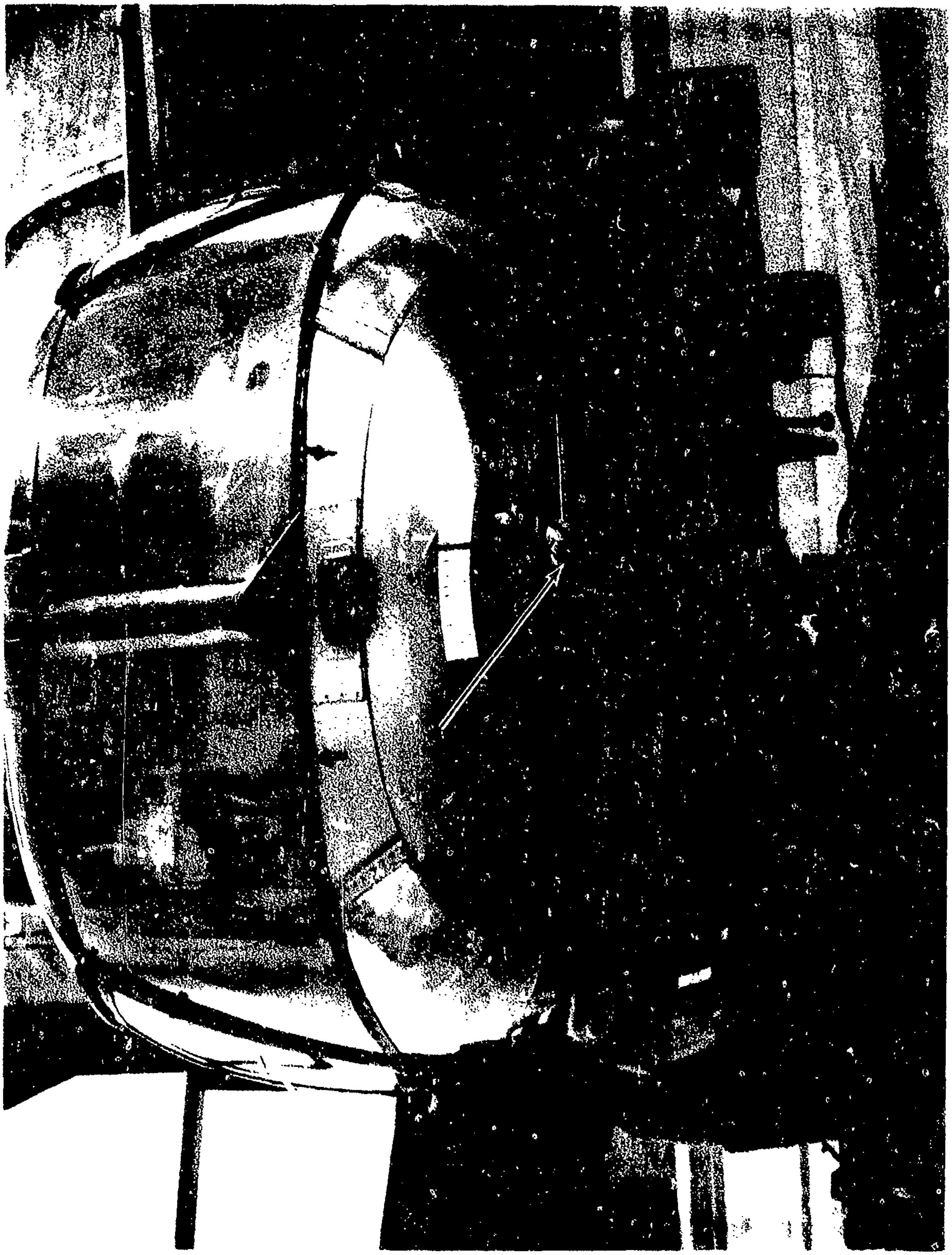


Figure A-41. SA-365N-1 air data boom.

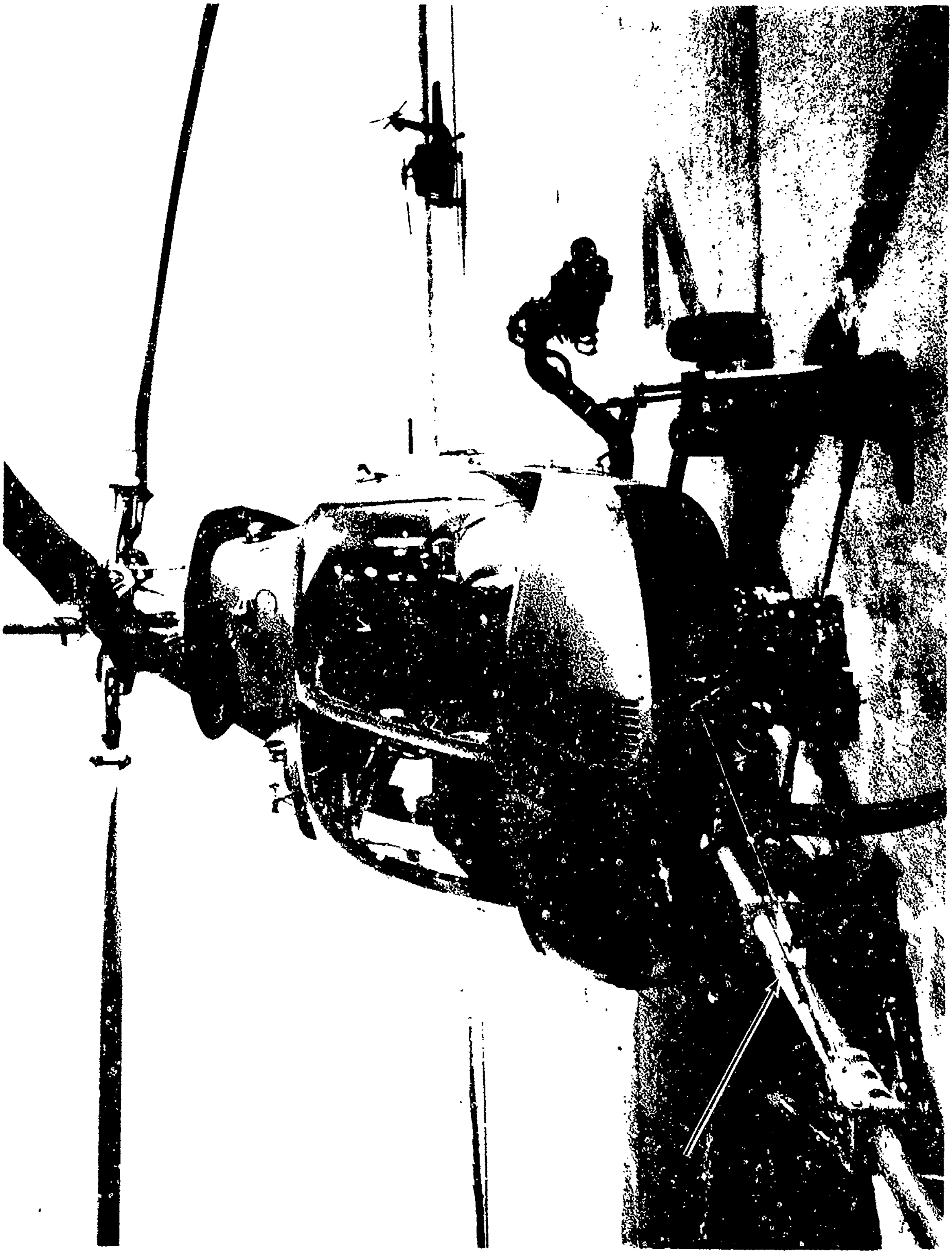


Figure A-42. 406 CS air data boom.

Figure A-43. AH-1S air data boom.

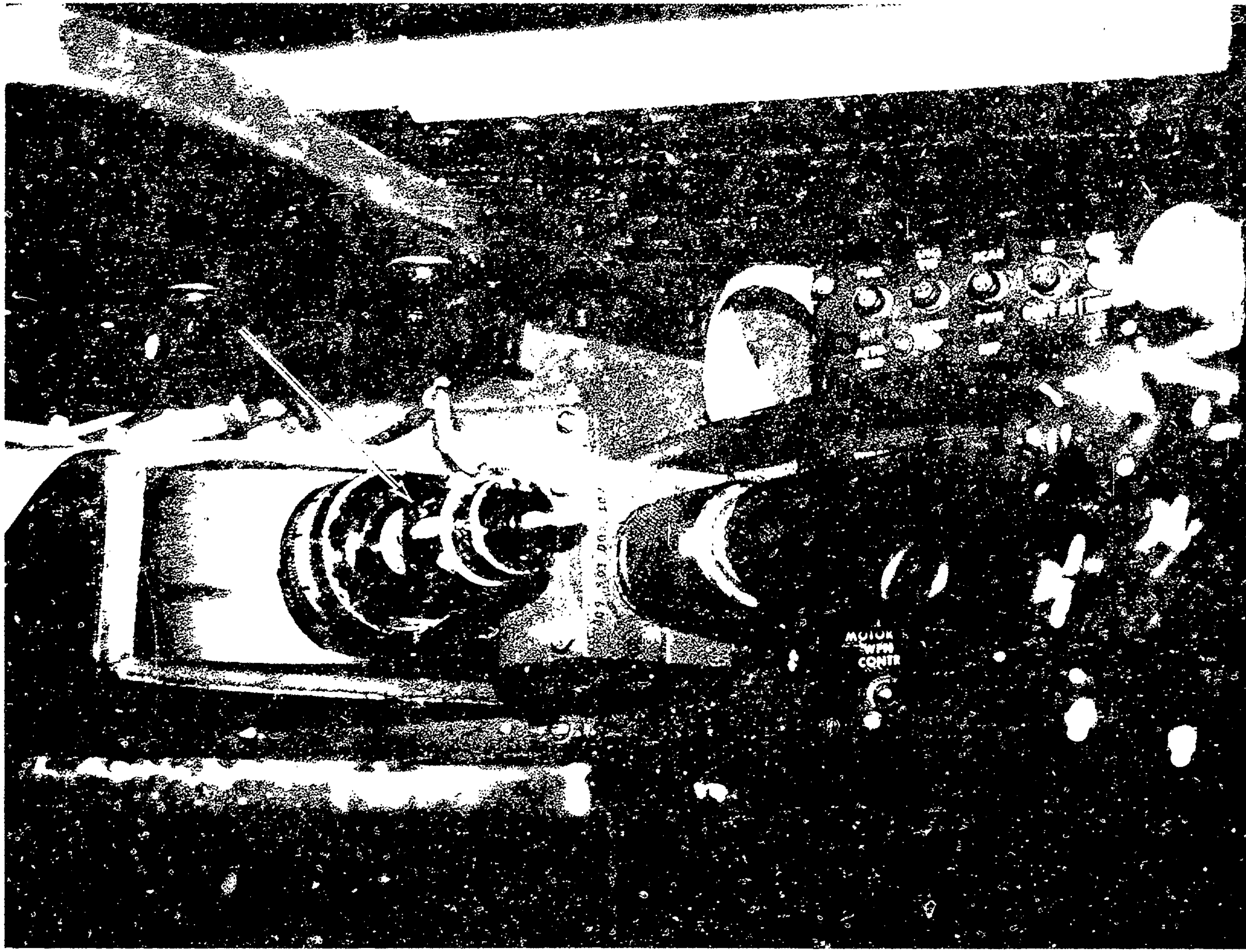


Figure A-44. AH-1S collective stick shaker.

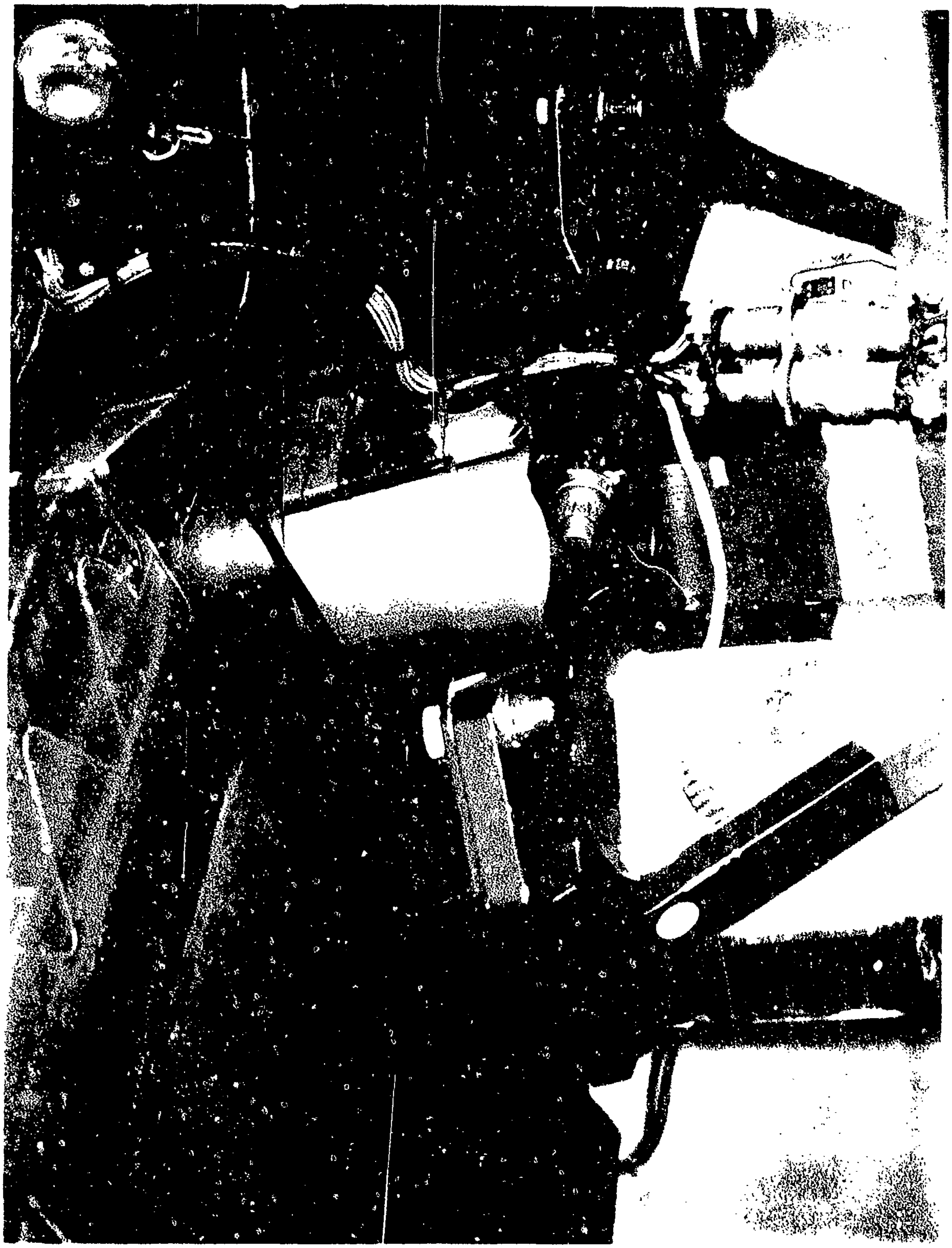


Figure A-45. AH-1S main rotor hub spring.

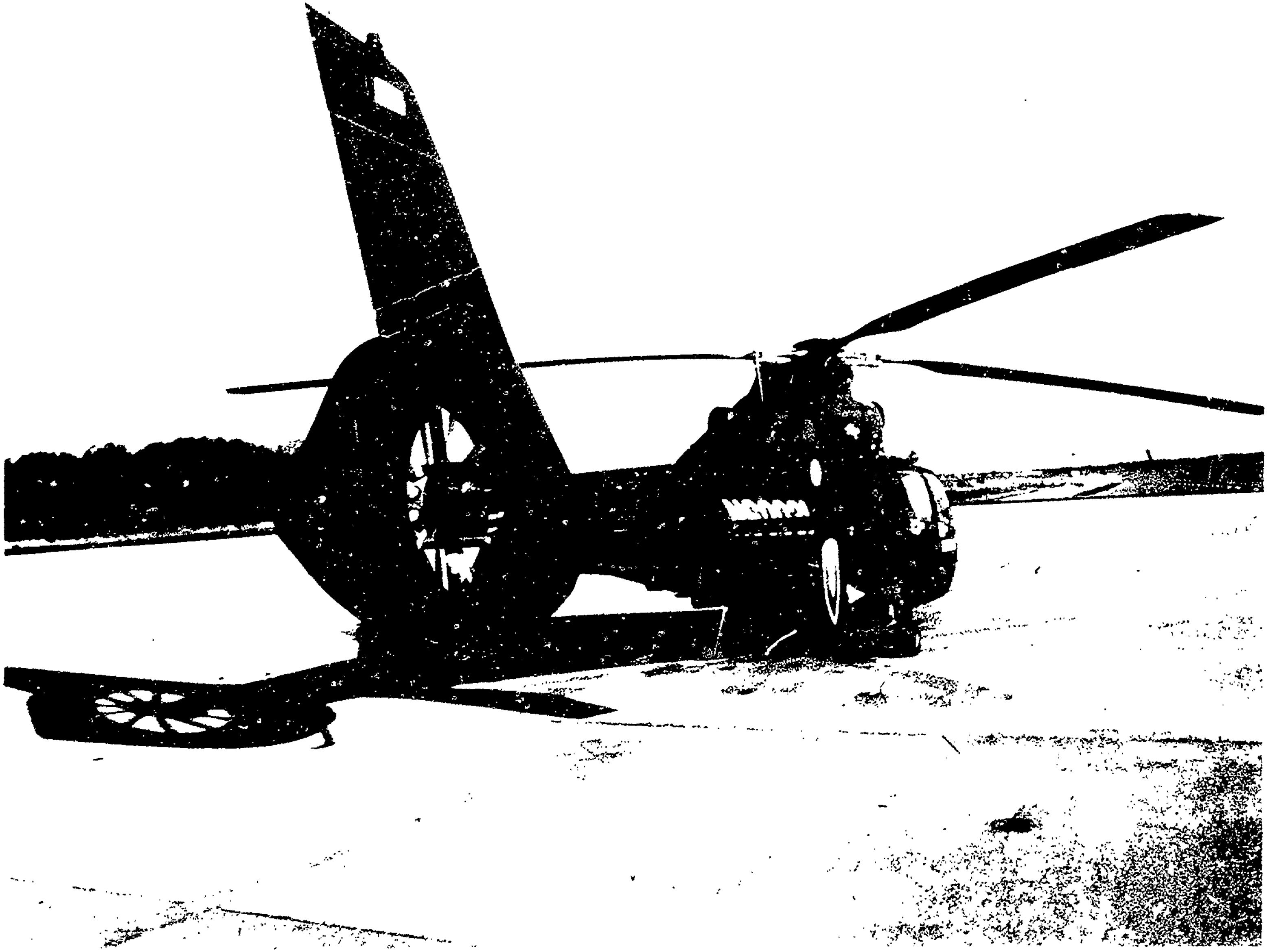


Figure A-46. SA-365N-1 Fenestron.

APPENDIX B
PARTICIPANTS

The participants in the AACT IV program and their primary contributions are as follows:

A. U.S. Army Aviation Applied Technology Directorate (AATD)
Fort Eustis, Virginia

-provided aircraft (AH-1S and SA-365N-1), project management, instrumentation support, engineering support, and a project pilot.

B. U.S. Naval Rotary Wing Aircraft Test Directorate (RWATD)
Patuxent River, Maryland

-provided maintenance support, instrumentation support, engineering support, test coordination, and a project pilot.

C. McDonnell Douglas Helicopter Company (MDHC)
Mesa, Arizona

-provided aircraft (AH-64A) project coordinator, operational and maintenance support, instrumentation support, flight test engineers, and two project pilots.

D. Bell Helicopter Textron Inc. (BHTI)
Fort Worth, Texas

-provided aircraft (406 CS), project coordinator, operational and maintenance support, instrumentation support, flight test engineer, and project pilot.

E. U.S. Naval Air Test Center (NATC)
Patuxent River, Maryland

-provided test range facilities and personnel under a subsidy agreement with AATD.

F. U.S. Army 268th Attack Helicopter Battalion, 9th Infantry Division
Fort Lewis, Washington

-provided one Air Combat Maneuver (ACM) Standardization Instructor Pilot (SIP).

G. Utah Army National Guard (UTARNG)
West Jordan, Utah

-provided one ACM SIP project pilot.

H. U.S. Army Aviation Engineering Flight Activity (USAAEFA)
Edwards Air Force Base, California

-provided a project pilot.

I. U.S. Naval Test Pilot School (USNTPS)
Naval Air Test Center
Patuxent River, Maryland

-provided a project pilot.

J. Aerospatiale Helicopter Corporation (AHC)
Grand Prairie, Texas

-provided SA-365N-1 special repair/maintenance support under contract to AATD.

K. Giravions Dorand

-provided laser weapons simulator maintenance support under contract to AATD.

L. Polhemus Navigation Sciences
Colchester, Vermont

-supported the AH-1S and 406 CS Helmet Mounted Sight (HMS) under contract to AATD.

M. Thomson CSF/Hamilton Standard
Hartford, Connecticut

-supported the SA-365N-1 Heads-Up Display (HUD) via AATD contract with AHC.

APPENDIX C
RULES OF ENGAGEMENT

A. All aircraft will maintain a minimum of 500 feet separation during all engagements, except 200 feet separation ($\pm$45 deg off the tail) is allowed during prebriefed "warm-up" tail chase operations.

B. Head on pass, nose high goes high, all aircraft will clear to the right (left to left pass). If right to right pass is desired or required, the initiating aircraft will call "Right to Right Pass" and the other aircraft will acknowledge "Roger, Right to Right Pass".

C. Helicopter minimum altitude for ACM will be 500 feet AGL. Maximum recommended altitude is 1500 feet AGL (2000 feet AGL for ACM).

D. All aircraft will maintain adherence to specified aircraft limits.

E. ACM will not be conducted into or through an overcast or undercast.

F. ACM flights will only be conducted during day VFR conditions.

G. All participating aircraft will have at least one common radio for air-to-air communications, and all aircraft will monitor guard frequencies at all times. Positive radio communications are required between all parties. Also, cockpit intercom is required.

H. The aggressor aircraft will disengage under the following conditions:

   1. At 500 feet range from the opponent or 200 feet in tail chase, $\pm$45 deg off the bogey's tail.

   2. Anytime altitude restrictions are broken.

   3. With loss of visual contact.

   4. If any aircraft loses positive radio communications, including intercom system (ICS). If radio failure occurs, resume level flight and rock your rotary wing.

   5. When any unsafe condition exists, real or perceived.

   6. When the learning and/or test objectives have been met.

7. Anytime nonparticipating aircraft enters the ACM training area without prior coordination.

8. Anytime a "knock it off" call is made. All "knock it off" calls will be acknowledged, "Roger, knock it off". Each aircraft will then immediately return to an unaccelerated, level flight condition.

I. All flight leaders are responsible for ensuring that the Rules of Engagement (ROE) are briefed prior to each sortie.

J. All "fights on" calls should be acknowledged, "Roger, fights on".

K. When adversaries are stacked vertically one above the other, the lower aircraft will not induce any vertical climb excursions with either power or pitch attitude. Adversaries will remain on predictable flight paths.

L. Either aircraft may call "Knock it off" with the loss of visual contact; however, if the vertical and/or horizontal separation or closure rates at the time of visual contact loss are perceived safe, a call of "No joy" from the "blind" aircraft should be answered by a call of "Continue" or "Knock it off" by the adversary aircraft. If "Continue" is called, that aircraft assumes responsibility for separation and closure rates of both aircraft until visual contact is again acquired and is acknowledged by "Tally" from the previously "blind" aircraft.

APPENDIX D
AH-1S (JAH-1F) SAFETY PRECAUTIONS/OPERATING LIMITATIONS

1. All limits of the operator's manual (Reference 4) apply.

2. Airspeed Limits:

a.	Maximum	190 KIAS
b.	Level flight & maneuver - per Figure 5-3 of operator's manual	
c.	Autorotation	120 KIAS
d.	Sideward	35 KIAS
e.	Rearward	30 KIAS
f.	SCAS OFF	100 KIAS
g.	Above 88% Q - 30-minute limit	

3. Attitude and Rate Limits:

a.	Pitch	+45 deg
b.	Roll	+90 deg
c.	Maximum pitch rate	+45 deg/sec, -15 deg/sec
d.	Maximum roll rate	60 deg/sec
e.	Maximum yaw rate	45 deg/sec

4. Control System Force Feedback: Reduce severity of maneuver upon occurrence; treat recovery as from blade stall and do not proceed to more extreme initial conditions.

5. Normal Acceleration Limits: +2.3g to +0.5g (see Figure D-1).

6. Rotor Speed Limits:

a.	Maximum continuous	105%
b.	Minimum continuous	91%
c.	Minimum transient	85%
d.	Nr for collective application in auto entry with	
	(1) Q > 55%	94%
	(2) Q < 55%	91%

7. Sideslip Limits: See Figure D-2.

8. Torque Limits:

a.	Continuous	0 - 88%
b.	30 minutes (below 100 KIAS)	88 - 100%
c.	Maximum	100%
d.	Autorotation entries and/or rapid throttle chops prohibited above 150 KIAS for torque greater than 62.5%.	

9. Mast Bumping (100% flapping; 12.5 deg): Observe flapping limit to 70% maximum allowable. Land immediately with minimal maneuvering/power changes should mast bumping occur.

10. Unusual attitude recovery from both high altitude pitch and roll maneuvers will be practiced during the instruction/demonstration flights at the beginning of this project. Unusual attitude recovery procedures will be thoroughly covered during the preflight brief of every subsequent data flight.

11. Hazards:

    a. Low G flight
    b. Causes/consequences of mast bumping
    c. Low rotor speed flight
    d. Transmission overtorque with left roll rate

12. Control of rotor speed at both the high and low end of the allowable speed range is critical and will be monitored by the pilots.

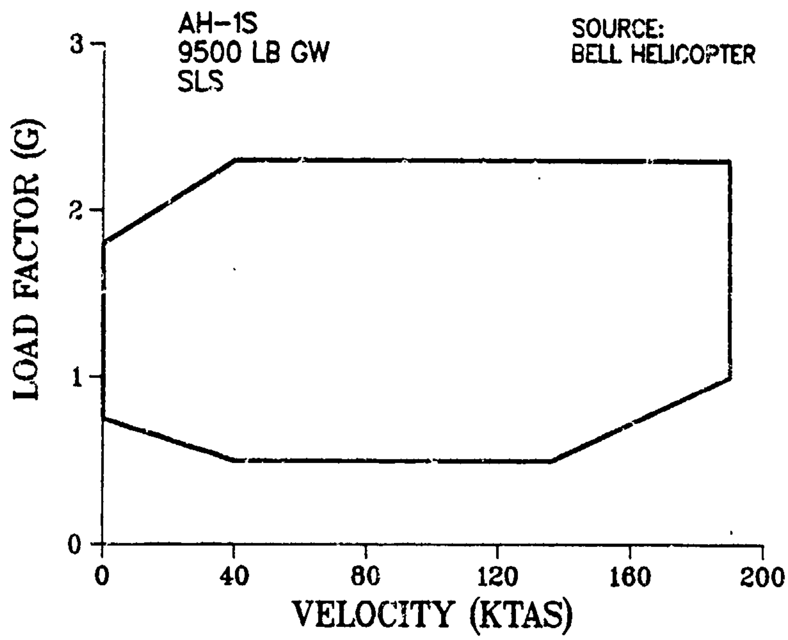


Figure D-1. AH-1S V-n envelope.

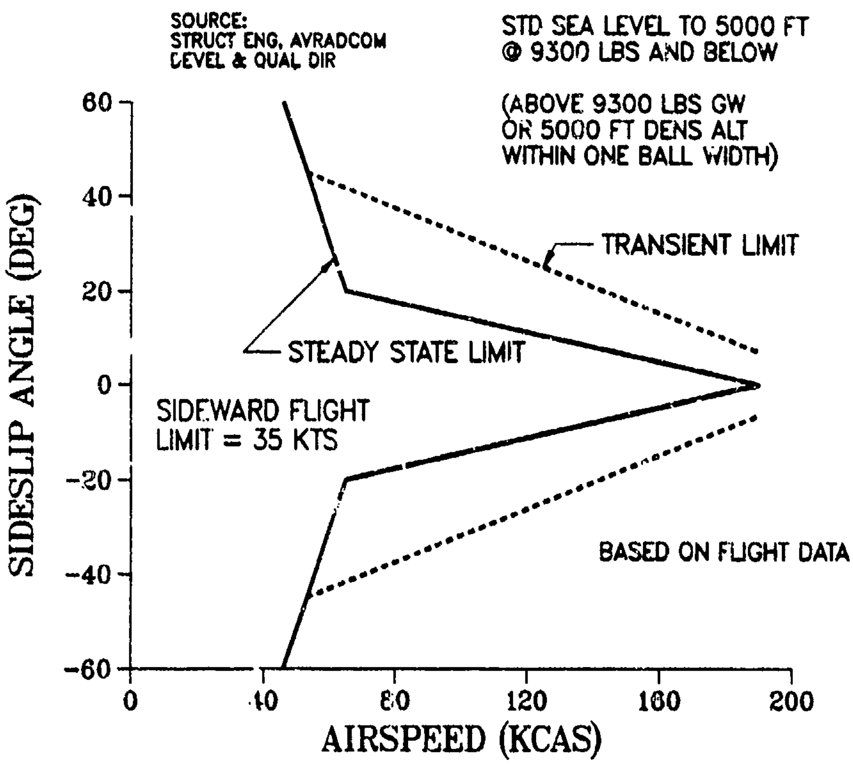


Figure D-2. AH-1S sideslip limits.

APPENDIX E
AH-64A SAFETY PRECAUTIONS/OPERATING LIMITATIONS

1. All limits of the pilot's manual (Reference 5) apply for the AACT IV tests.

2. Gross weight/center of gravity: See Figures E-1 and E-2.

3. Airspeed Limits:

a.	V_h (Maximum in level flight at MCP)	164 KTAS
b.	Maximum (dive)	197 KTAS
c.	Autorotation	143 KTAS
d.	Sideward	45 KTAS
e.	Rearward	45 KTAS

4. Normal Acceleration Limits: +3.5g to -0.5g (see Figure E-3); +2.75g to 0.0g at AACT IV test weight of 16,200 lb.

5. Sideslip Limits: See Figure E-4.

6. Rotor Speed Limits:

a.	Limit, power-off	376 rpm
b.	Limit, power-on	361 rpm
c.	Maximum (redline), power-off	301 rpm
d.	Minimum (redline), power-off	261 rpm
e.	Maximum, power-on (100%)	289 rpm
f.	Minimum, power-on (94%)	272 rpm

7. Attitude and Rate Limits:

a.	Pitch*	+90 deg ABSOLUTE (knock it off)
b.	Roll*	+120 deg ABSOLUTE (knock it off)
c.	Maximum pitch rate	50 deg/sec
d.	Maximum roll rate	110 deg/sec
e.	Maximum yaw rate	limited by sideslip envelope

*As determined by the MDHC transient all-attitude evaluation tests, March 1987.

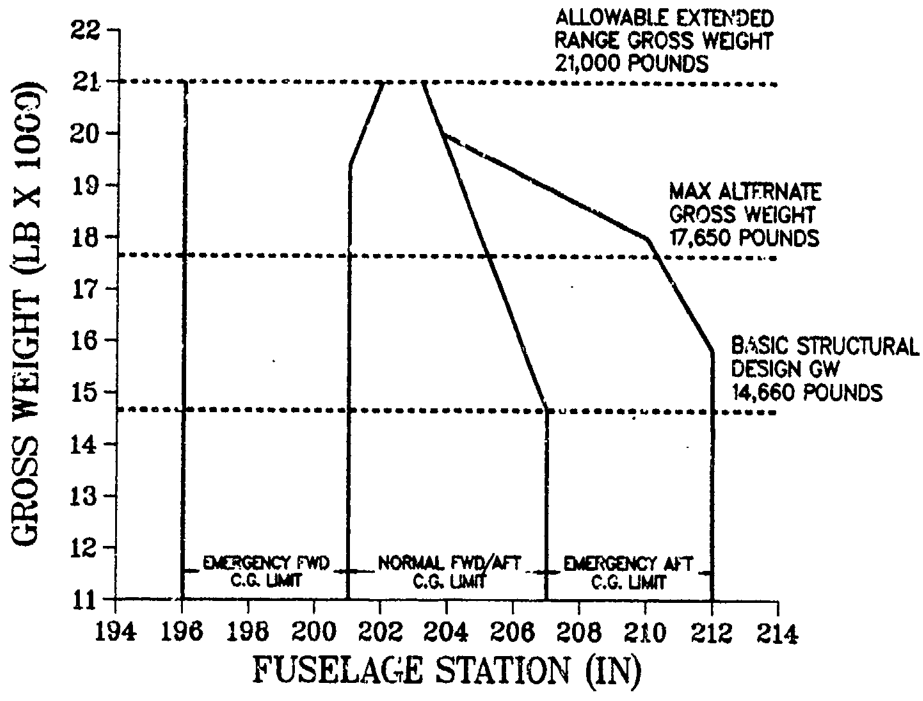


Figure E-1. AH-64A longitudinal center of gravity range and limits.

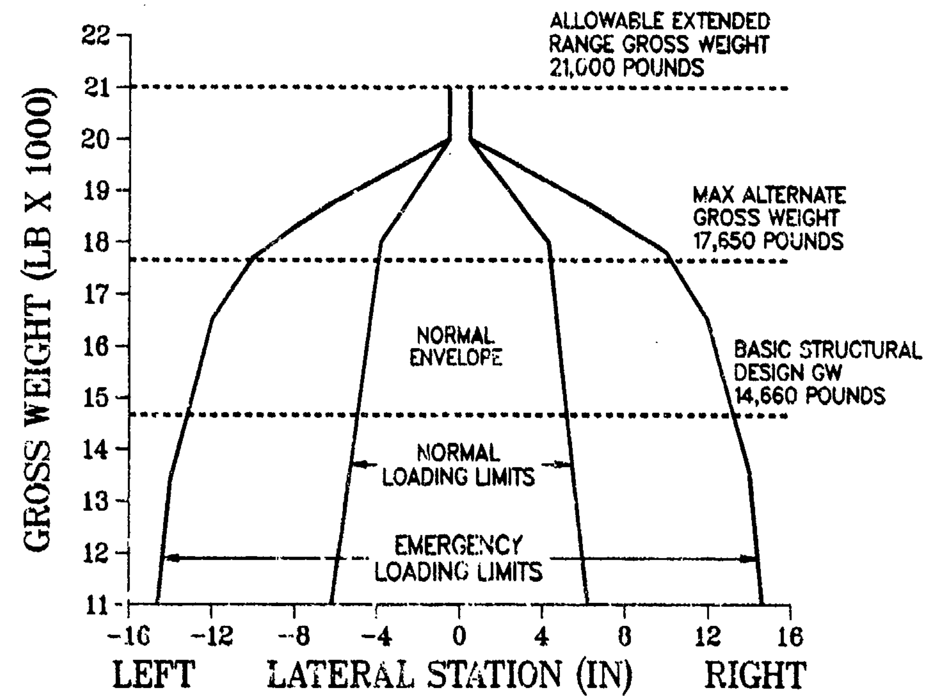


Figure E-2. AH-64A lateral center of gravity range and limits.

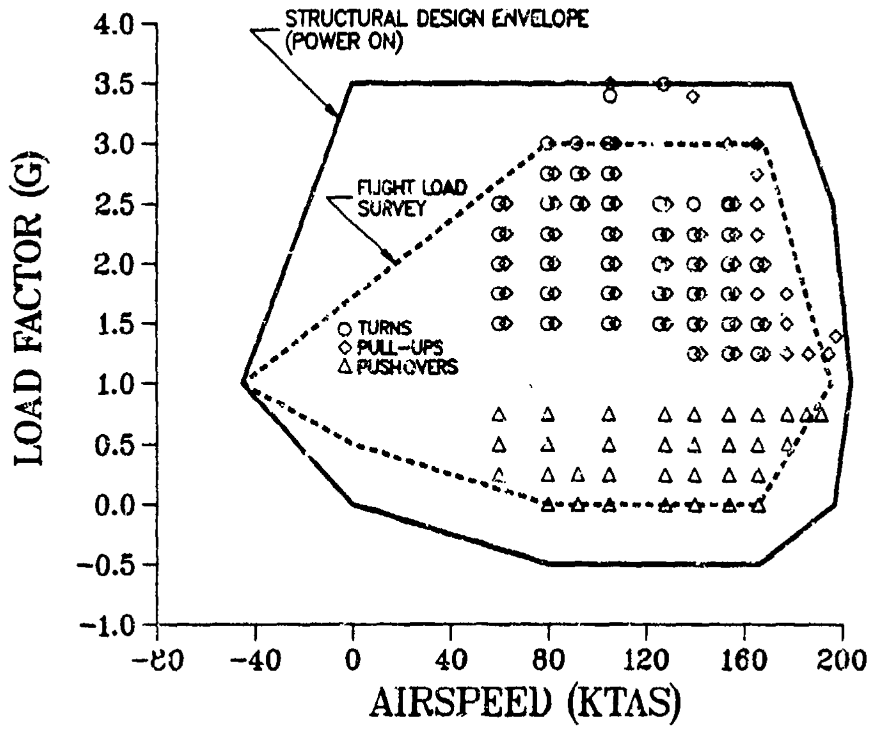


Figure E-3. AH-64A V-n diagram with load survey test points.

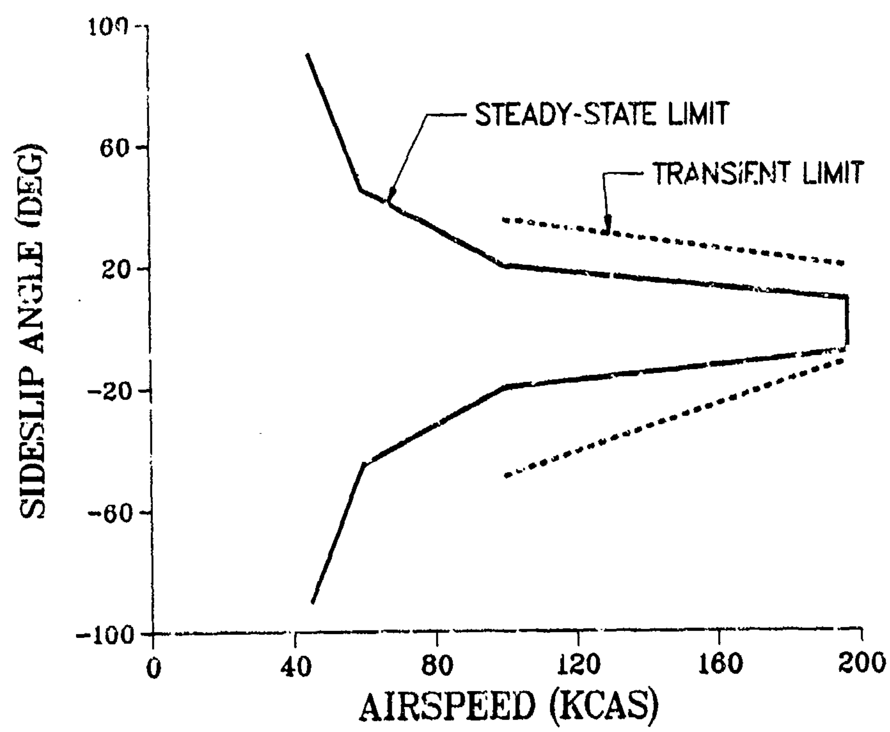


Figure E-4. AH-64A sideslip limits.

APPENDIX F

SA-365N-1 SAFETY PRECAUTIONS/OPERATING LIMITATIONS

1. Except as noted below the helicopter must be operated in accordance with the limitations contained in the FAA-approved Rotorcraft Flight Manual (Reference 6) supplied with the helicopter.

2. Airspeed Limits:

a.	Max, landing gear operating and landing gear extended	135 KIAS
b.	Vmax (V_{NE})	175 KIAS
c.	Autorotation	135 KIAS
d.	Sideward/rearward	40 KIAS

3. Attitude and Angular Rate Limits:

a.	Pitch	+60 deg (observe load factor limits)
b.	Roll	+90 deg (observe load factor limits)
c.	Pitch rate	50 deg/sec
d.	Roll rate	60 deg/sec
e.	Yaw rate	60 deg/sec

4. Normal Acceleration: 0 to 2.7 G, as shown in Figure F-1.

5. Sideslip Limits: See Figure F-2.

6. Rotor Speed Limits:

a.	Maximum continuous, power-on	365 rpm (dual engine)
b.	Minimum continuous, power-on	340 rpm (dual engine)
c.	Maximum continuous, power-off	420 rpm
d.	Minimum continuous, power-off	320 rpm
e.	Maximum emergency, transient	420 rpm power-off
f.	Minimum emergency, transient	295 rpm power-off

7. Torque Limits:

   a. Maximum permissible twin-engine torque:

      (1) For yaw control in hover, total torque — 110%

      (2) Hover and forward flight — 100%

b. Maximum permissible singe-engine torque:

(1)	Maximum transient (20-sec) rating	69%
(2)	Maximum 2.5 minute rating	61%
(3)	Maximum continuous rating	59%

8. Longitudinal CG Position: 3.84m - 4.00m

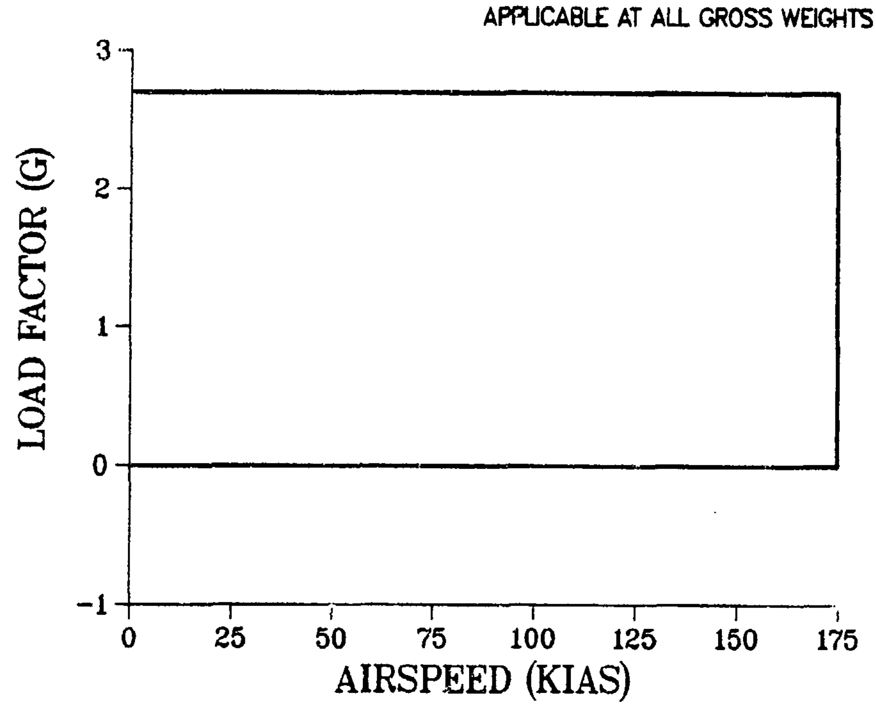


Figure F-1. Aerospatiale SA-365N-1 V-n diagram.

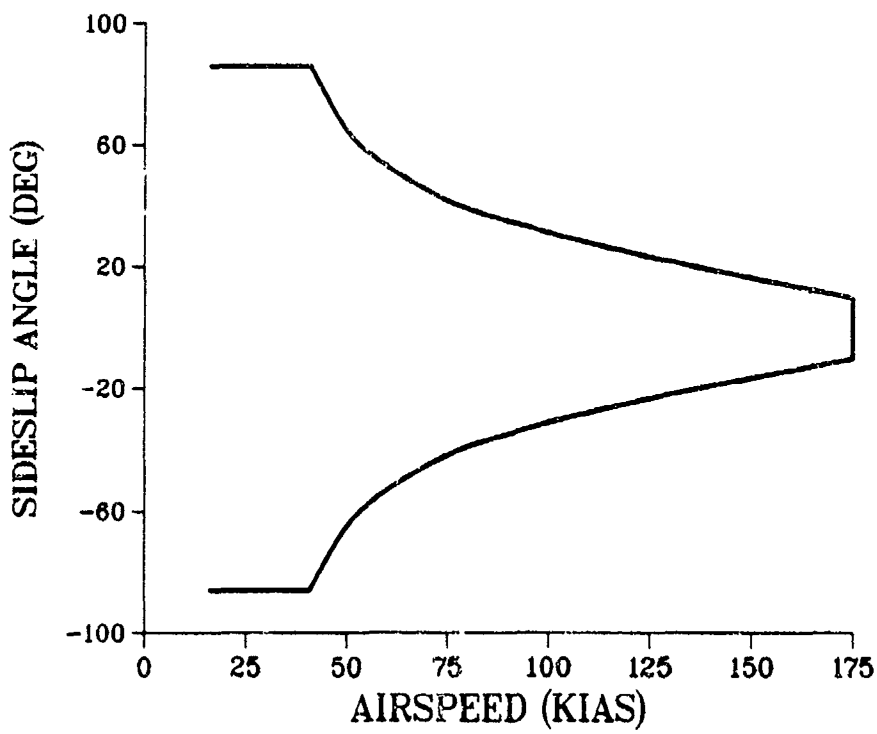


Figure F-2. Aerospatiale SA-365N-1 sideslip envelope.

APPENDIX G
406 CS SAFETY PRECAUTIONS/OPERATING LIMITATIONS

1. All limits of the Model 406 CS operations manual (Reference 7) apply.

2. Airspeed Limits:

a.	Maximum	130 KCAS
b.	Level flight and maneuvers (see Figure G-1)	
c.	Autorotations	100 KCAS
d.	Sideward	35 KCAS
e.	Rearward	35 KCAS

3. Attitude and Angular Rate Limits:

a.	Pitch attitude	+60 deg (see Figures G-2 & G-3)
b.	Roll attitude	+90 deg (see Figure G-4)
c.	Maximum pitch rate	+45 deg/sec, -30 deg/sec; (see Figures G-2 & G-3)
d.	Maximum roll rate	90 deg/sec (see Figure G-4)
e.	Maximum yaw rate	45 deg/sec

4. Normal Acceleration Limits: +2.5g max @ 4500 lb; 0.0 min @ all gross weights (see Figure G-5)

5. Sideslip Limits: See Figure G-6.

6. Rotor Speed Limits:

		Continuous	Transient
a.	Power-On		
	(1) Maximum (100%)	395 rpm	422 rpm
	(2) Minimum (97%)	382 rpm	355 rpm
b.	Power-Off		
	(1) Maximum (107%)	422 rpm	
	(2) Minimum (90%)	355 rpm	

7. Power Turbine Limits:

a.	Power-Off Maximum	107% (Nr Limited)
b.	Power-On Maximum	100% (Nr Limited)

c.	Transient	119% (Power Off 15-sec max) 109% (at Intermediate Power 15-sec max)

8. Torque Limits (Transmission Limited):

a.	Continuous Inflight	455 SHP @ 395 Nr (72,598 in-lb)
b.	Transient (10-sec)	637 SHP @ 395 Nr (101,638 in-lb)

9. Hazards:

   a. High yaw rates can cause tail rotor flapping contact.
   b. Avoid rotor speeds below 64% (253 rpm) during termination of autorotation landing.

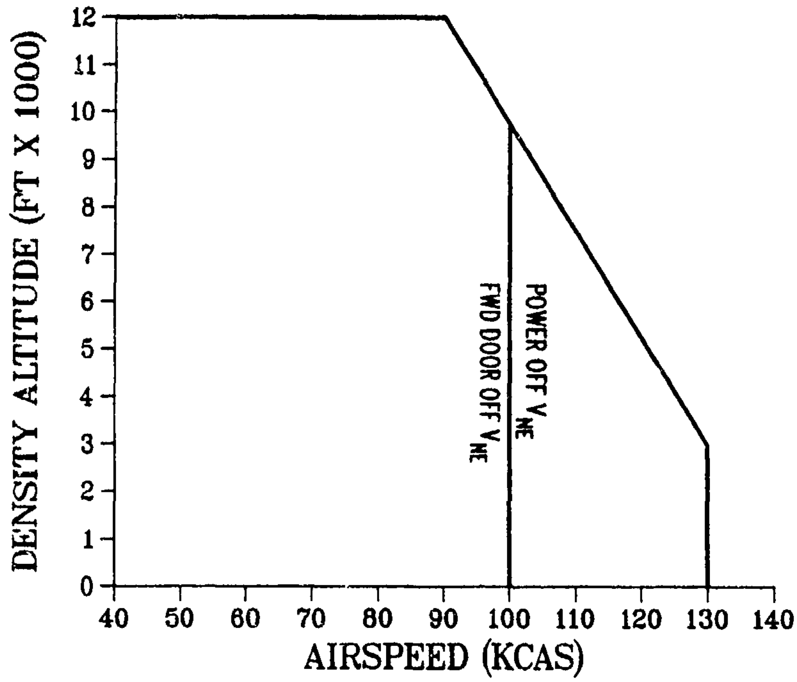


Figure G-1. 406 CS airspeed operating limits.

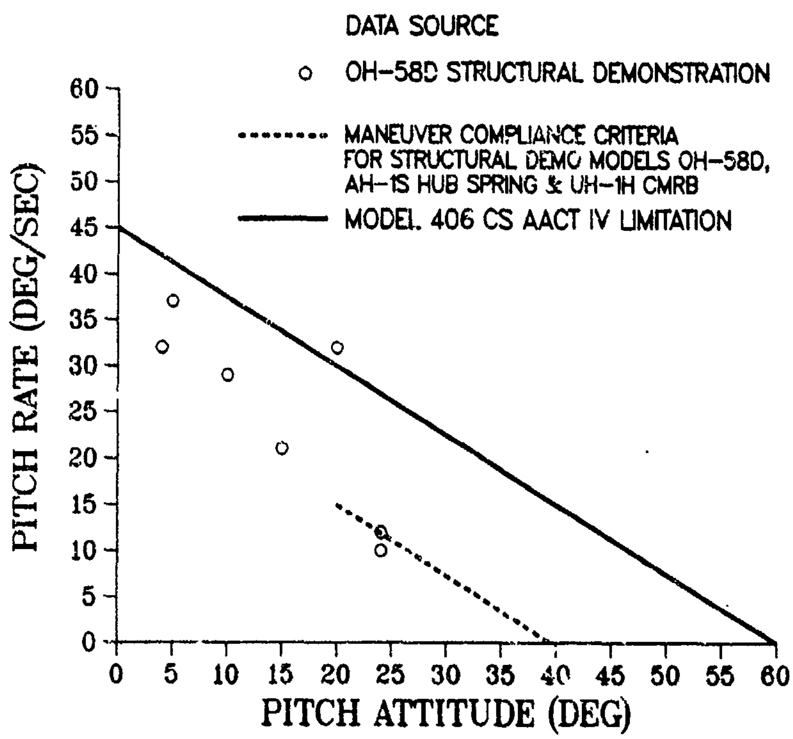


Figure G-2. 406 CS nose-up pitch rate vs pitch attitude limitations.

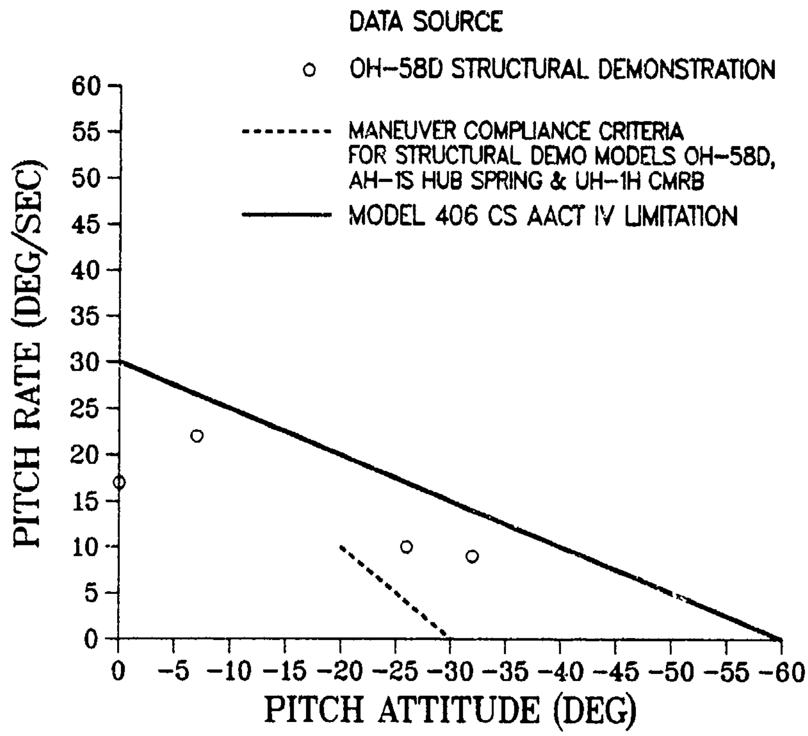


Figure G-3. 406 CS nose-down pitch rate vs pitch attitude limitations.

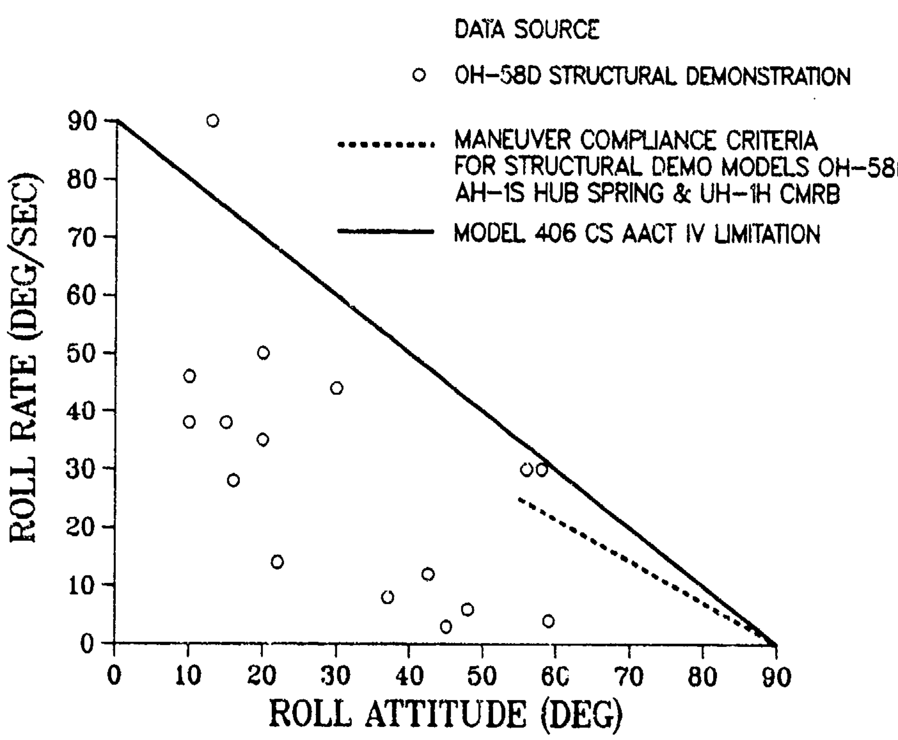


Figure G-4. 406 CS roll rate vs roll attitude limitations.

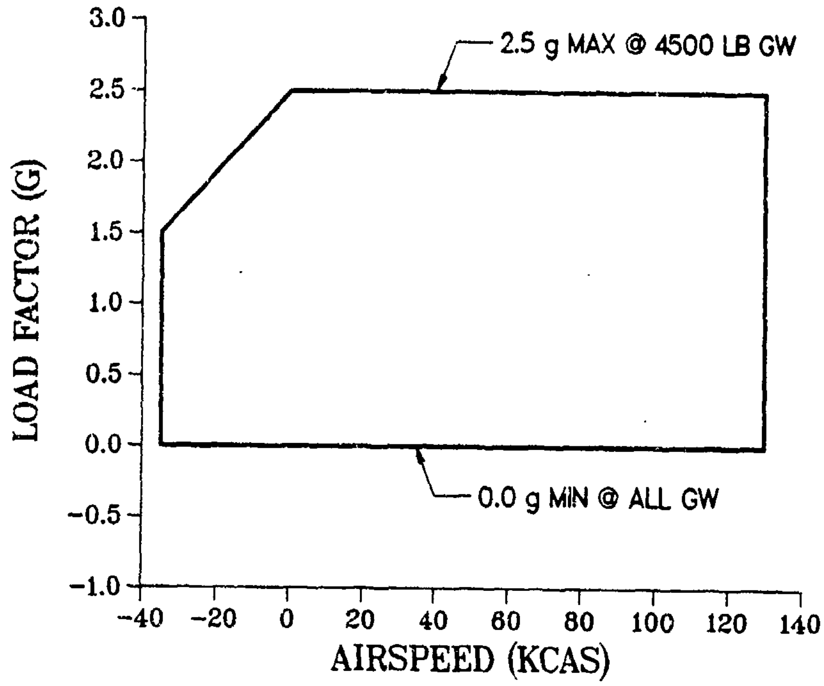


Figure G-5. 406 CS maneuver load factor envelope.

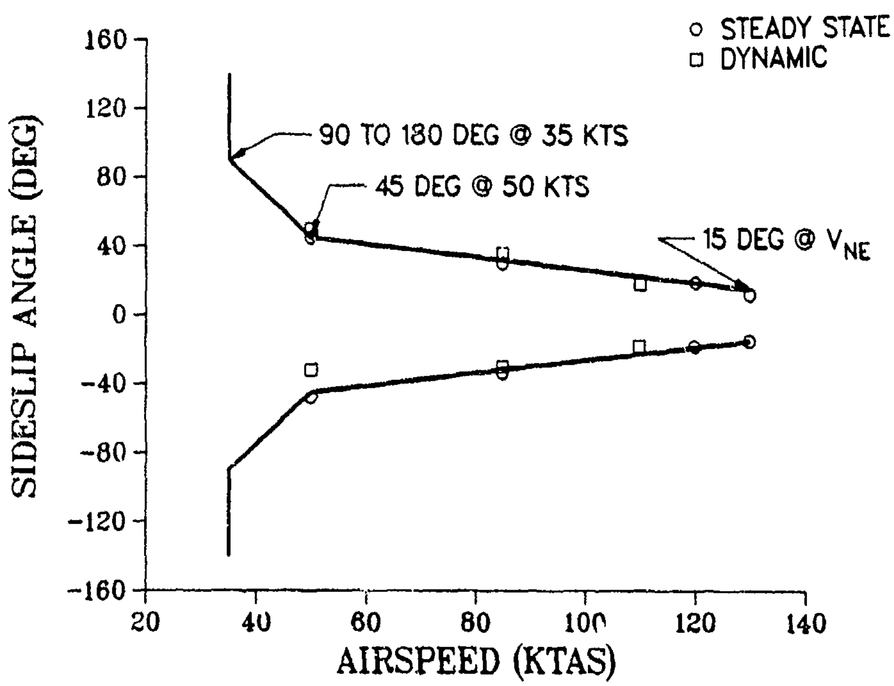


Figure G-6. 406 CS sideslip limits.

APPENDIX H
DATAMAP INSTRUMENTATION PARAMETERS

AH-64A versus 406 CS

(F12.4,105E12.6,12X)

TIME	TIME	SECONDS
VOLT	AH64 PCM EXCITATION VOLTAGE	VOLTS
PRES	AH64 PACER AMBIENT AIR PRESSURE	PSIA
VEL1	AH64 AIRSPEED	KNOTS
DUM1	DUMMY	
TAS2	AH64 TRUE AIRSPEED FORE-AFT PACER ADS	KNOTS
ALT2	AH64 ALTITUDE	FEET
PSIA	PSIA	PSIA
DLR2	AH64 ROLL RATE AT STATION 200	DEG/SEC
DLP2	AH64 PITCH RATE AT STATION 200	DEG/SEC
DLY2	AH64 YAW RATE AT STATION 200	DEG/SEC
MRZ1	AH64 MAIN ROTOR AZIMUTH INDEX	COUNTS
RACC	AH64 CG ROLL ANGULAR ACCELERATION	DEG/SEC2
PACC	AH64 CG PITCH ANGULAR ACCELERATION	DEG/SEC2
YACC	AH64 CG YAW ANGULAR ACCELERATION	DEG/SEC2
LAT1	AH64 LATERAL CONTROL POSITION	PERCENT
RAP1	AH64 ROLL ACTUATOR POSITION	PERCENT
RSAP	AH64 ROLL SAS ACTUATOR POSITION	PERCENT
YAW1	AH64 YAW ATTITUDE	DEGREES
LTOR	AH64 LEFT ENGINE TORQUE	FT-LBS
RTOR	AH64 RIGHT ENGINE TORQUE	FT-LBS
PED1	AH64 PEDAL POSITION	PERCENT
YAP1	AH64 YAW ACTUATOR POSITION	PERCENT
YSAP	AH64 YAW SAS ACTUATOR POSITION	PERCENT
COL1	AH64 COLLECTIVE POSITION	PERCENT
CPAP	AH64 COLLECTIVE PITCH ACTUATOR POSITION	PERCENT
SSL1	AH64 PACER SIDESLIP ANGLE	DEGREES
XAC2	AH64 CG LONGITUDINAL ACCEL STA 200	G'S
YAC2	AH64 CG LATERAL ACCEL STA 200	G'S
DLP1	AH64 PITCH RATE (SHIP)	DEG/SEC
DLR1	AH64 ROLL RATE (SHIP)	DEG/SEC
DLY1	AH64 YAW RATE (SHIP)	DEG/SEC
NRR1	AH64 MAIN ROTOR SPEED	PERCENT
LGAS	AH64 LEFT ENGINE GAS TEMPERATURE	DEG C
GGG1	AH64 CG VERTICAL ACCELERATION STA 200	G'S
PIT1	AH64 PITCH ATTITUDE	DEGREES
LPTS	AH64 LEFT ENG. POWER TURBINE SPEED	PERCENT
RGAS	AH64 RIGHT ENGINE GAS TEMPERATURE	PERCENT
ROL1	AH64 ROLL ATTITUDE	DEGREES
RPTS	AH64 RIGHT ENG. POWER TURBINE SPEED	PERCENT
TAT1	AH64 TOTAL AIR TEMPERATURE	DEG C
OAT1	AH64 PACER OUTSIDE AIR TEMPERATURE	DEG C
LON1	AH64 LONGITUDINAL CONTROL POSITION	PERCENT
PAP1	AH64 PITCH ACTUATOR POSITION	PERCENT
PSP1	AH64 PITCH SAS ACTUATOR POSITION	PERCENT
NRR5	406 MAIN ROTOR RPM	RPM

DLY5 406 YAW RATE	DEG/SEC
VEL5 406 COARSE AIRSPEED	KNOTS
EVN5 406 EVENT MARKER	COUNTS
NPP5 406 NP	PERCENT
HHH5 406 ALTITUDE	FEET
DLP5 406 PITCH RATE	DEG/SEC
SSL5 406 SIDESLIP ANGLE	DEGREES
NGG5 406 NG	PERCENT
DLR5 406 ROLL RATE	DEG/SEC
COL5 406 COLLECTIVE POSITION	PERCENT
ROL5 406 ROLL ATTITUDE	DEGREES
PED5 406 PEDAL POSITION	PERCENT
PIT5 406 PITCH ATTITUDE	DEGREES
FAP5 406 F/A STICK POSITION	PERCENT
TEL5 406 TURRET ELEVATION	DEGREES
LAT5 406 LATERAL STICK POSITION	PERCENT
TAZ5 406 TURRET AZIMUTH	DEGREES
EGT5 406 EXHAUST GAS TEMPERATURE	DEG C
FTM5 406 FUEL TEMPERATURE	DEG C
EQT5 406 ENGINE TORQUE	PSIA
GGG5 406 CG LOAD FACTOR	G'S
FFR5 406 FUEL FLOW RATE	GAL/HR
XXX2 AH64A TO 406CS X (E-W)	FEET
YYY2 AH64A TO 406CS Y (N-S)	FEET
ZZZ2 AH64A TO 406CS Z	FEET
XXX1 CTR TO AH64A X	FEET
YYY1 CTR TO AH64A Y	FEET
ZZZ1 CTR TO AH64A Z	FEET
TAS1 AH64A TRUE AIRSPEED (RADAR)	KNOTS
ALT1 AH64A ALTITUDE (RADAR)	FEET
HED1 AH64A HEADING (RADAR)	DEGREES
XXX5 CTR TO 406CS X	FEET
YYY5 CTR TO 406CS Y	FEET
ZZZ5 CTR TO 406CS Z	FEET
TAS5 406CS TRUE AIRSPEED (RADAR)	KNOTS
ALT5 406CS ALTITUDE (RADAR)	FEET
HED5 406CS HEADING (RADAR)	DEGREES
GSP1 AH64A GROUND SPEED	KNOTS
GTR1 AH64A GROUND TRACK	DEGREES
AZM2 406CS TO AH64A AZIMUTH	DEGREES
ELV2 406CS TO AH64A ELEVATION	DEGREES
RNG2 406CS TO AH64A RANGE	FEET
AZV2 406CS TO AH64A AZIMUTH VELOCITY	DEG/SEC
ELR2 406CS TO AH64A ELEVATION VELOCITY	DEG/SEC
RGV2 406CS TO AH64A RANGE VELOCITY	FT/SEC
RLB2 406CS TO AH64A RELATIVE BEARING	DEGREES
RLB3 AH64A TO 406CS RELATIVE BEARING	DEGREES
TCA2 406CS TO AH64A T.C.A.	FEET
LTS2 406CS TO AH64A LATERAL SEPARATION	FEET
LNS2 406CS TO AH64A LONGITUDINAL SEPARATION	FEET
RNG1 CTR TO AH64A RANGE	FEET
RNG5 CTR TO 406CS RANGE	FEET

ESH1	AH64A ESUBH FROM A/C DATA	FEET
ESH6	AH64A ESUBH FROM CTR DATA	FEET
ESH5	406CS ESUBH FROM A/C DATA	FEET
ESH2	406CS ESUBH FROM CTR DATA	FEET
PSS1	AH64A PSUBS FROM A/C DATA	FT/SEC
PSS6	AH64A PSUBS FROM CTR DATA	FT/SEC
PSS5	406CS PSUBS FROM A/C DATA	FT/SEC
PSS2	406CS PSUBS FROM CTR DATA	FT/SEC
IRIG	IRIG TIME	SECONDS

AH-64A versus SA-365N-1

(F12.4,133E12.6,12X)

TIME	TIME	SECONDS
VOLT	AH64 PCM EXCITATION VOLTAGE	VOLTS
PRES	AH64 PACER AMBIENT AIR PRESSURE	PSIA
VEL1	AH64 AIRSPEED	KNOTS
DUM1	DUMMY	
TAS2	AH64 TRUE AIRSPEED FORE-AFT PACER ADS	KNOTS
ALT2	AH64 ALTITUDE	FEET
PSIA	PSIA	PSIA
DLR2	AH64 ROLL RATE AT STATION 200	DEG/SEC
DLP2	AH64 PITCH RATE AT STATION 200	DEG/SEC
DLY2	AH64 YAW RATE AT STATION 200	DEG/SEC
MRZ1	AH64 MAIN ROTOR AZIMUTH INDEX	COUNTS
RACC	AH64 CG ROLL ANGULAR ACCELERATION	DEG/SEC2
PACC	AH64 CG PITCH ANGULAR ACCELERATION	DEG/SEC2
YACC	AH64 CG YAW ANGULAR ACCELERATION	DEG/SEC2
LAT1	AH64 LATERAL CONTROL POSITION	PERCENT
RAP1	AH64 ROLL ACTUATOR POSITION	PERCENT
RSAP	AH64 ROLL SAS ACTUATOR POSITION	PERCENT
YAW1	AH64 YAW ATTITUDE	DEGREES
LTOR	AH64 LEFT ENGINE TORQUE	FT-LBS
RTOR	AH64 RIGHT ENGINE TORQUE	FT-LBS
PED1	AH64 PEDAL POSITION	PERCENT
YAP1	AH64 YAW ACTUATOR POSITION	PERCENT
YSAP	AH64 YAW SAS ACTUATOR POSITION	PERCENT
COL1	AH64 COLLECTIVE POSITION	PERCENT
CPAP	AH64 COLLECTIVE PITCH ACTUATOR POSITION	PERCENT
SSL1	AH64 PACER SIDESLIP ANGLE	DEGREES
XAC2	AH64 CG LONGITUDINAL ACCEL STA 200	G'S
YAC2	AH64 CG LATERAL ACCEL STA 200	G'S
DLP1	AH64 PITCH RATE (SHIP)	DEG/SEC
DLR1	AH64 ROLL RATE (SHIP)	DEG/SEC
DLY1	AH64 YAW RATE (SHIP)	DEG/SEC
NRR1	AH64 MAIN ROTOR SPEED	PERCENT
LGAS	AH64 LEFT ENGINE GAS TEMPERATURE	DEG C
GGG1	AH64 CG VERTICAL ACCELERATION STA 200	G'S
PIT1	AH64 PITCH ATTITUDE	DEGREES
LPTS	AH64 LEFT ENG. POWER TURBINE SPEED	PERCENT
RGAS	AH64 RIGHT ENGINE GAS TEMPERATURE	PERCENT

ROL1	AH64 ROLL ATTITUDE	DEGREES
RPTS	AH64 RIGHT ENG. POWER TURBINE SPEED	PERCENT
TAT1	AH64 TOTAL AIR TEMPERATURE	DEG C
OAT1	AH64 PACER OUTSIDE AIR TEMPERATURE	DEG C
LON1	AH64 LONGITUDINAL CONTROL POSITION	PERCENT
PAP1	AH64 PITCH ACTUATOR POSITION	PERCENT
PSP1	AH64 PITCH SAS ACTUATOR POSITION	PERCENT
SLT5	SA365 SAS LATERAL-LEFT	PERCENT
SLN5	SA365 SAS LONGITUDINAL	PERCENT
VEL5	SA365 AIRSPEED	KNOTS
SYW5	SA365 SAS YAW	PERCENT
A0A5	SA365 ANGLE OF ATTACK	DEGREES
ALT6	SA365 ALTITUDE	FEET
MF15	SA365	
MF25	SA365	
PIT5	SA365 PITCH ATTITUDE	DEGREES
ROL5	SA365 ROLL ATTITUDE	DEGREES
DLP5	SA365 PITCH RATE	DEG/SEC
DLR5	SA365 ROLL RATE	DEG/SEC
DLY5	SA365 YAW RATE	DEG/SEC
MBP5	SA365 MAIN ROTOR BLADE PITCH	DEGREES
SF15	SA365 SWASH-PLATE FORCE F1	POUNDS
SF25	SA365 SWASH-PLATE FORCE F2	POUNDS
SF35	SA365 SWASH-PLATE FORCE F3	POUNDS
FF15	SA365 FUEL FLOW RATE ENGINE 1	GAL/HR
FF25	SA365 FUEL FLOW RATE ENGINE 2	GAL/HR
NG15	SA365 NG ENGINE 1	PERCENT
NG25	SA365 NG ENGINE 2	PERCENT
NP15	SA365 NP ENGINE 1	PERCENT
NP25	SA365 NP ENGINE 2	PERCENT
NRR5	SA365 MAIN ROTOR RPM	PERCENT
EQ15	SA365 TORQUE ENGINE 1	PSI
EQ25	SA365 TORQUE ENGINE 2	PSI
TT15	SA365 TOT ENGINE 1	DEG C
TT25	SA365 TOT ENGINE 2	DEG C
ROC5	SA365 RATE OF CLIMB	FT/MIN
HRD5	SA365 RADAR ALTITUDE	FEET
OAT5	SA365 OUTSIDE AIR TEMPERATURE	DEG C
PED5	SA365 PEDAL POSITION	PERCENT
COL5	SA365 COLLECTIVE STICK POSITION	PERCENT
LON5	SA365 LONGITUDINAL STICK POSITION	PERCENT
LAT5	SA365 LATERAL STICK POSITION	PERCENT
SSL5	SA365 SIDESLIP ANGLE	DEGREES
DLY6	SA365 YAW RATE	DEG/SEC
DLP6	SA365 PITCH RATE	DEG/SEC
DLR6	SA365 ROLL RATE	DEG/SEC
GGG5	SA365 VERTICAL ACCELERATION	G'S
LNG5	SA365 LONGITUDINAL ACCELERATION	G'S
LTG5	SA365 LATERAL ACCELERATION	G'S
HED5	SA365 HEADING	DEGREES
MRQ5	SA365 MAIN ROTOR TORQUE	FT-LBS
TRQ5	SA365 TAIL ROTOR TORQUE	FT-LBS

XS15 SA365 TRANSMISSION LOAD 1	POUNDS
XS25 SA365 TRANSMISSION LOAD 2	POUNDS
XS35 SA365 TRANSMISSION LOAD 3	POUNDS
XS45 SA365 TRANSMISSION LOAD 4	POUNDS
TRG5 SA365 TRIGGER PULL	ON/OFF
SLT6 SA365 SAS LATERAL-RIGHT	PERCENT
XXX2 AH64A TO SA365 X (E-W)	FEET
YYY2 AH64A TO SA365 Y (N-S)	FEET
ZZZ2 AH64A TO SA365 Z	FEET
XXX1 CTR TO AH64A X	FEET
YYY1 CTR TO AH64A Y	FEET
ZZZ1 CTR TO AH64A Z	FEET
TAS1 AH64A TRUE AIRSPEED (RADAR)	KNOTS
ALT1 AH64A ALTITUDE (RADAR)	FEET
HED1 AH64A HEADING (RADAR)	DEGREES
XXX5 CTR TO SA365 X	FEET
YYY5 CTR TO SA365 Y	FEET
ZZZ5 CTR TO SA365 Z	FEET
TAS5 SA365 TRUE AIRSPEED (RADAR)	KNOTS
ALT5 SA365 ALTITUDE (RADAR)	FEET
HED5 SA365 HEADING (RADAR)	DEGREES
GSP1 AH64A GROUND SPEED	KNOTS
GTR1 AH64A GROUND TRACK	DEGREES
AZM2 SA365 TO AH64A AZIMUTH	DEGREES
ELV2 SA365 TO AH64A ELEVATION	DEGREES
RNG2 SA365 TO AH64A RANGE	FEET
AZV2 SA365 TO AH64A AZIMUTH VELOCITY	DEG/SEC
ELR2 SA365 TO AH64A ELEVATION VELOCITY	DEG/SEC
RGV2 SA365 TO AH64A RANGE VELOCITY	FT/SEC
RLB2 SA365 TO AH64A RELATIVE BEARING	DEGREES
RLB3 AH64A TO SA365 RELATIVE BEARING	DEGREES
TCA2 SA365 TO AH64A T.C.A.	DEGREES
LTS2 SA365 TO AH64A LATERAL SEPARATION	FEET
LNS2 SA365 TO AH64A LONGITUDINAL SEPARATION	FEET
RNG1 CTR TO AH64A RANGE	FEET
RNG5 CTR TO SA365 RANGE	FEET
ESH1 AH64A ESUBH FROM A/C DATA	FEET
ESH6 AH64A ESUBH FROM CTR DATA	FEET
ESH5 SA365 ESUBH FROM A/C DATA	FEET
ESH2 SA365 ESUBH FROM CTR DATA	FEET
PSS1 AH64A PSUBS FROM A/C DATA	FT/SEC
PSS6 AH64A PSUBS FROM CTR DATA	FT/SEC
PSS5 SA365 PSUBS FROM A/C DATA	FT/SEC
PSS2 SA365 PSUBS FROM CTR DATA	FT/SEC
IRIG IRIG TIME	SECONDS

AH-64A versus AH-1S

(F11.4,122E12.6,12X)	
TIME TIME	SECONDS
VOLT AH64 PCM EXCITATION VOLTAGE	VOLTS

PRES	AH64 PACER AMBIENT AIR PRESSURE	PSIA
VEL1	AH64 AIRSPEED	KNOTS
DUM1	DUMMY	
TAS2	AH64 TRUE AIRSPEED FORE-AFT PACER ADS	KNOTS
ALT2	AH64 ALTITUDE	FEET
PSIA	PSIA	PSIA
DLR2	AH64 ROLL RATE AT STATION 200	DEG/SEC
DLP2	AH64 PITCH RATE AT STATION 200	DEG/SEC
DLY2	AH64 YAW RATE AT STATION 200	DEG/SEC
MRZ1	AH64 MAIN ROTOR AZIMUTH INDEX	COUNTS
RACC	AH64 CG ROLL ANGULAR ACCELERATION	DEG/SEC2
PACC	AH64 CG PITCH ANGULAR ACCELERATION	DEG/SEC2
YACC	AH64 CG YAW ANGULAR ACCELERATION	DEG/SEC2
LAT1	AH64 LATERAL CONTROL POSITION	PERCENT
RAP1	AH64 ROLL ACTUATOR POSITION	PERCENT
RSAP	AH64 ROLL SAS ACTUATOR POSITION	PERCENT
YAW1	AH64 YAW ATTITUDE	DEGREES
LTOR	AH64 LEFT ENGINE TORQUE	FT-LBS
RTOR	AH64 RIGHT ENGINE TORQUE	FT-LBS
PED1	AH64 PEDAL POSITION	PERCENT
YAP1	AH64 YAW ACTUATOR POSITION	PERCENT
YSAP	AH64 YAW SAS ACTUATOR POSITION	PERCENT
COL1	AH64 COLLECTIVE POSITION	PERCENT
CPAP	AH64 COLLECTIVE PITCH ACTUATOR POSITION	PERCENT
SSL1	AH64 PACER SIDESLIP ANGLE	DEGREES
XAC2	AH64 CG LONGITUDINAL ACCEL STA 200	G'S
YAC2	AH64 CG LATERAL ACCEL STA 200	G'S
DLP1	AH64 PITCH RATE (SHIP)	DEG/SEC
DLR1	AH64 ROLL RATE (SHIP)	DEG/SEC
DLY1	AH64 YAW RATE (SHIP)	DEG/SEC
NRR1	AH64 MAIN ROTOR SPEED	PERCENT
LGAS	AH64 LEFT ENGINE GAS TEMPERATURE	DEG C
GGG1	AH64 CG VERTICAL ACCELERATION STA 200	G'S
PIT1	AH64 PITCH ATTITUDE	DEGREES
LPTS	AH64 LEFT ENG. POWER TURBINE SPEED	PERCENT
RGAS	AH64 RIGHT ENGINE GAS TEMPERATURE	PERCENT
ROL1	AH64 ROLL ATTITUDE	DEGREES
RPTS	AH64 RIGHT ENG. POWER TURBINE SPEED	PERCENT
TAT1	AH64 TOTAL AIR TEMPERATURE	DEG C
OAT1	AH64 PACER OUTSIDE AIR TEMPERATURE	DEG C
LON1	AH64 LONGITUDINAL CONTROL POSITION	PERCENT
PAP1	AH64 PITCH ACTUATOR POSITION	PERCENT
PSP1	AH64 PITCH SAS ACTUATOR POSITION	PERCENT
NRR5	AH1S MAIN ROTOR RPM	PERCENT
HED5	AH1S HEADING	DEGREES
VEL5	AH1S AIRSPEED	KNOTS
SSL5	AH1S SIDESLIP ANGLE	DEGREES
AOA5	AH1S ANGLE OF ATTACK	DEGREES
ALT5	AH1S ALTITUDE	FEET
LSA5	AH1S LASSI A	KNOTS
LSB5	AH1S LASSI B	KNOTS
PIT5	AH1S PITCH ATTITUDE	DEGREES

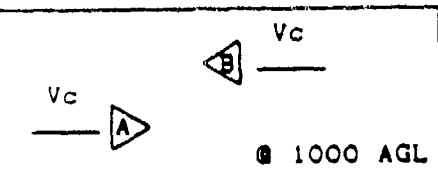
ROL5 AH1S ROLL ATTITUDE	DEGREES
DLP5 AH1S PITCH RATE	DEG/SEC
DLR5 AH1S ROLL RATE	DEG/SEC
DLY5 AH1S YAW RATE	DEG/SEC
EQT5 AH1S ENGINE TORQUE PRESSURE	PSI
N2R5 AH1S N2	PERCENT
N1R5 AH1S N1	PERCENT
FFR5 AH1S FUEL FLOW RATE	GAL/HR
EGT5 AH1S EXHAUST GAS TEMPERATURE	DEG C
SCR5 AH1S SCAS ROLL	PERCENT
XR15 AH1S AXIAL STRAP FORCE 1	LBS
XR25 AH1S AXIAL STRAP FORCE 2	LBS
XP15 AH1S AXIAL SUPPORT FORCE 1	LBS
XP25 AH1S AXIAL SUPPORT FORCE 2	LBS
CLB5 AH1S COLLECTIVE BOOST-TUBE FORCE	LBS
CLK5 AH1S COLLECTIVE STICK FORCE	LBS
FSK5 AH1S FORE-AFT STICK FORCE	LBS
LTK5 AH1S LATERAL STICK FORCE	LBS
TQL5 AH1S OVER-TORQUE LIGHT INDICATOR	ON/OFF
GGG5 AH1S VERTICAL ACCELERATION	G'S
GFA5 AH1S LONGITUDINAL ACCELERATION	G'S
GLT5 AH1S LATERAL ACCELERATION	G'S
GTZ5 AH1S GUN TURRET AZIMUTH	DEGREES
GTV5 AH1S GUN TURRET ELEVATION	DEGREES
SCY5 AH1S SCAS YAW	PERCENT
COL5 AH1S COLLECTIVE STICK POSITION	PERCENT
LAT5 AH1S LATERAL STICK POSITION	PERCENT
LON5 AH1S LONGITUDINAL STICK POSITION	PERCENT
PED5 AH1S PEDAL POSITION	PERCENT
ROC5 AH1S RATE OF CLIMB	FT/MIN
STT5 AH1S STATUS WORD	
XXX2 AH64A TO AH1S X (E-W)	FEET
YYY2 AH64A TO AH1S Y (N-S)	FEET
ZZZ2 AH64A TO AH1S Z	FEET
XXX1 CTR TO AH64A X	FEET
YYY1 CTR TO AH64A Y	FEET
ZZZ1 CTR TO AH64A Z	FEET
TAS1 AH64A TRUE AIRSPEED (RADAR)	KNOTS
ALT1 AH64A ALTITUDE (RADAR)	FEET
HED1 AH64A HEADING (RADAR)	DEGREES
XXX5 CTR TO AH1S X	FEET
YYY5 CTR TO AH1S Y	FEET
ZZZ5 CTR TO AH1S Z	FEET
TAS5 AH1S TRUE AIRSPEED (RADAR)	KNOTS
ALT5 AH1S ALTITUDE (RADAR)	FEET
HED5 AH1S HEADING (RADAR)	DEGREES
GSP1 AH64A GROUND SPEED	KNOTS
GTR1 AH64A GROUND TRACK	DEGREES
AZM2 AH1S TO AH64A AZIMUTH	DEGREES
ELV2 AH1S TO AH64A ELEVATION	DEGREES
RNG2 AH1S TO AH64A RANGE	FEET
AZV2 AH1S TO AH64A AZIMUTH VELOCITY	DEG/SEC

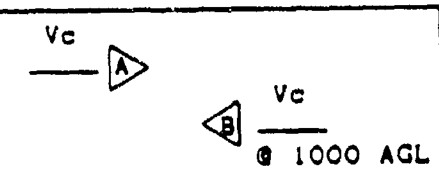
ELR2	AH1S TO AH64A ELEVATION VELOCITY	DEG/SEC
RGV2	AH1S TO AH64A RANGE VELOCITY	FT/SEC
RLB2	AH1S TO AH64A RELATIVE BEARING	DEGREES
RLB3	AH64A TO AH1S RELATIVE BEARING	DEGREES
TCA2	AH1S TO AH64A T.C.A.	FEET
LTS2	AH1S TO AH64A LATERAL SEPARATION	FEET
LNS2	AH1S TO AH64A LONGITUDINAL SEPARATION	FEET
RNG1	CTR TO AH64A RANGE	FEET
RNG5	CTR TO AH1S RANGE	FEET
ESH1	AH64A ESUBH FROM A/C DATA	FEET
ESH6	AH64A ESUBH FROM CTR DATA	FEET
ESH5	AH1S ESUBH FROM A/C DATA	FEET
ESH2	AH1S ESUBH FROM CTR DATA	FEET
PSS1	AH64A PSUBS FROM A/C DATA	FT/SEC
PSS6	AH64A PSUBS FROM CTR DATA	FT/SEC
PSS5	AH1S PSUBS FROM A/C DATA	FT/SEC
PSS2	AH1S PSUBS FROM CTR DATA	FT/SEC
IRIG	IRIG TIME	SECONDS

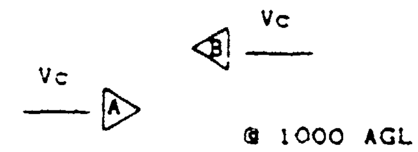
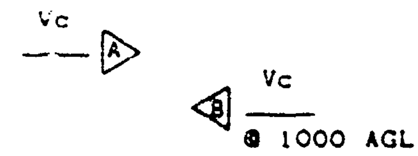
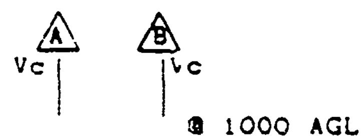
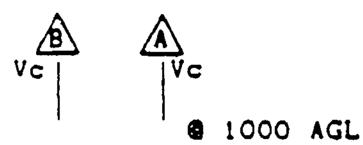
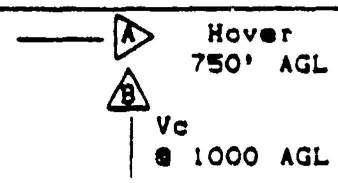
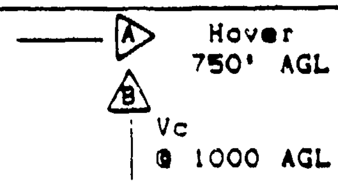
APPENDIX I
DESCRIPTIONS OF MANEUVER INITIAL CONDITIONS

AACT-IV FLIGHT DATA CARD

<table>
<tr><th>Event</th><th colspan="2">Description</th></tr>
<tr><td>1A</td><td colspan="2">"EYEBALL RANGE" A/C Silhouette Checks 2500, 1500, 500, 200 ft.</td></tr>
<tr><td>1B</td><td colspan="2">Static Laser Check & Altimeter Comparison.</td></tr>
<tr><td>2A
2A-1
2A-2
2A-3</td><td colspan="2">Tail Chase - (A) Attacker / (B) Bogey 30 deg. Orbit.
High YoYo: (A) 100 kts. / (B) 80 kts.
Low YoYo: (A) 80 kts. / (B) 100 kts.
Free Combinations: @ 100 kts.</td></tr>
<tr><td>2A
2A-1
2A-2
2A-3</td><td colspan="2">Tail Chase - (A) Bogey 30 deg. Orbit / (B) Attacker.
High YoYo: (A) 80 kts. / (B 100 kts.
Low YoYo: (A) 100 kts. / (B) 80 kts.
Free Combinations: @ 100 kts.</td></tr>
<tr><td>3A
3A-1
3A-2</td><td colspan="2">Head to Head - (A) Attacker / (B) Bogey Straight.
30 deg. Pop Turn. (A) 100 kts., 1000 ft. AGL.
40 deg. Pop Turn. " " " "</td></tr>
<tr><td>3A
3A-1
3A-2</td><td colspan="2">Head to Head - (A) Bogey Straight / (B) Attacker.
30 deg. Pop Turn. (A) 100 kts., 1000 ft. AGL.
40 deg. Pop Turn. " " " "</td></tr>
<tr><td>4A/B</td><td colspan="2">Deleted</td></tr>
<tr><td>5A/B

5A
5B</td><td colspan="2">Head On Pass - (Left to Left), (Evasive Maneuvering-EVM),
(1500' Horz. Sep.), & (A Calls fights-on)
(A) Shooter / (B) EVM
(A) EVM / (B) Shooter</td></tr>
<tr><td></td><td>
</td><td>notes</td></tr>
<tr><td>5C/D

5C
5D</td><td colspan="2">Head On Pass - (Right to Right), (Evasive Maneuvering-EVM),
(1500' Horz. Sep.), & (A calls fights-on).
(A) Shooter / (B) EVM
(A) EVM / (B) Shooter</td></tr>
<tr><td></td><td>
</td><td>notes</td></tr>
</table>

<table>
<tr><td>6A</td><td colspan="2">Head On Pass - (Left to Left). (Fights-On Abeam "10 o'clock" (700' Horz. Sep.). & (A calls fights-on).</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
<tr><td>6B</td><td colspan="2">Head On Pass - (Right to Right). (Fights-On Abeam. "2 o'clock"). (700' Horz. Sep.). & (A calls fights-on).</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
<tr><td>7A</td><td colspan="2">Side by Side - 1000' Horz. Sep. (A calls fights-on)</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
<tr><td>7B</td><td colspan="2">Side by Side - 1000' Horz. Sep. (A calls fights-on)</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
<tr><td>8A</td><td colspan="2">Abeam Flyover - 150 ' Horz. Sep. (B calls fights-on)</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
<tr><td>8B</td><td colspan="2">Abeam Flyover - 0' Horz. Sep. (A calls fights-on)</td></tr>
<tr><td></td><td></td><td>notes</td></tr>
</table>

AACT-IV FLIGHT DATA CARD CONT.

9A	Abeam Flyover - 1500' Horz. Sep. (A calls fights-on)	
	B Hover 750' AGL A Vc @ 1000 AGL	notes
9B	Abeam Flyover - 0' Horz. Sep. (B calls fights-on)	
	B Hover 750' AGL A Vc @ 1000 AGL	notes
10A	Tail Chase - 1500' Horz. Sep. (B calls fights-on)	
	A Vc B Vc @ 750 AGL	notes
10B	Tail Chase - 1500' Horz. Sep. (A calls fights-on)	
	B Vc A Vc @ 750 AGL	notes
11A	Tail Chase - 1000' Horz. Sep. (B calls fights-on)	
	A Vc B Vc @ 750 AGL	notes
11B	Tail Chase - 1000' Horz. Sep. (A calls fights-on)	
	B Vc A Vc @ 750 AGL	notes

APPENDIX J
AACT IV FLIGHT ENGAGEMENT DATA MANAGEMENT NOMENCLATURE

The numbering nomenclature principally used in the AACT data base access includes the following information: The AACT number (4̲18013 = AACT 4), the flight number (4<u>18</u>013 = flight number 18), and the maneuver number (418<u>013</u> = maneuver number 13). Also note that the flight numbers and maneuver numbers correspond to flight numbers and event numbers detailed in Table 3 and Appendix I, respectively.

The aircraft combinations under each flight number in the following table are annotated with the particular fire control/gun configuration:

(F) - Fixed gun
(T) - Turreted gun
(MT) - Manual Turret gun (IHADSS)
(AT) - Automatic Turret gun (TADS)

FLT CARD	FLIGHT 05	FLIGHT 06	FLIGHT 08	FLIGHT 11	FLIGHT 15	FLIGHT 17
EVENT	64A(F)-406(F)	64A(MT)-406(F)	64A(AT)-406(F)	64A(F)-365(F)	64A(MT)-365(F)	64A(AT)-365(F)
5A		406002	408002	411009	415001	417001
5B		406003	408003	411010	415002	
5C	405006	406004	408004	411011	415003	417003,4
5D	405007	406005	408005	411012	415004	
6A	405008	406006	408007	411013	415005	417005
6B	405009	406007	408008	411014	415006	417006
7A	405010	406009	408010	411016	415007	
7B	405011	406011	408012	411017		
8A	405013	406013		411018		417012
8B	405016	406015		411019		417008
9A		406018				
9B	405017	406019		411021		
10A		406020	408013	411022	415008	417009
10B		406021	408014	411023		

	FLIGHT 12	FLIGHT 18	FLIGHT 19	FLIGHT 13	FLIGHT 14
	64A(F)-1S(F)	64A(F)-1S(T)	64A(AT)-1S(T)	365(F)-1S(F)	365(F)-1S(T)
5A			419003		414(01
5B	412002	418107	419004		414002
5C	412003		419005	413004	414003
5D	412004	418003	419006	413005	414004
6A	412021	418019	419007		414005
6B	412022	418020	419008	413006	414019
7A	412008	418007	419010	413008	
7B	412009	418006	419009	413007	414009
8A	412010	418008	419011	413009	414010
8B	412012	418009	419012	413010	414011
9A	412013	418011	419013	413011	
9B	412014	418012		413012	414012
10A	412017	418013	419015	413013	414014
10B	412018	418014	419016	413014	414015

APPENDIX K

EQUATIONS

Blade Area	$BA = bcR$
Disc Area	$DA = \pi R^2$
Blade Loading	$BL = W/bcR$
Power Loading	$PL = W/hp$
Disc Loading	$DL = W/\pi R^2$
Solidity	$\sigma = bcR/\pi R^2 = BA/DA$
Blade Loading Coefficient	$C_T/\sigma = \dfrac{T}{\rho \pi R^2 (\Omega R)^2} \cdot \dfrac{\pi R^2}{bcR} = \dfrac{(W)\ G}{\rho\ bcR(\Omega R)^2}$
Rotor Blade Inertia	$I_B = \int mr^2\, dr$
Lock Number	$LN = c\rho\ a\ R^4/I_B$
Tip Speed	$\text{Tip Speed} = \Omega R$
Time Constant	$\tau = 1/Mq$
Control Sensitivity	$\text{Control Sensitivity} = \dfrac{\text{Control Power}}{\text{Rotor Damping}}$

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

a	lift curve slope of blade section, 1/rad
AACT	air-to-air combat tests
AATD	Aviation Applied Technology Directorate
ACM	air combat maneuver
ADA	air defense artillery
ADSS	air data sensor system
AEFA	Aviation Engineering Flight Activity
AFB	Air Force base
AGL	above ground level
AHC	Aerospatiale Helicopter Company
ALES	Air Land Engagement Simulation
ANOVA	analysis of variance
AOS	angle of sight
AR	Army regulation
ASE	aircraft survivability equipment
ATAC	air-to-air combat
ATAM	air-to-air missile
ATAS	air-to-air Stinger
ATC	air traffic control
AVSCOM	Aviation Systems Command
b	number of blades
BA	blade area
BHTI	Bell Helicopter Textron Inc.
BL	blade loading
BRL	Ballistics Research Laboratory
c	blade chord, ft
CFT	captive flight trainer
CG	center of gravity
CPG	copilot/gunner
CS	Combat Scout
CSD	Computer Services Directorate
C_T	coefficient of thrust
C_T/σ	blade loading coefficient
CTR	Chesapeake Test Range
dm	differential of mass, slugs
DA	disk area
DATAMAP	data management and analysis package
DL	disk loading
DOF	degree-of-freedom
DTF	data transfer file

DVO	direct view optics
DW	digital word
EVM	evasive maneuvering
FAAD	forward area air defense
FCC	fire control computer
FLIR	forward-looking infrared
FM	frequency modulation
FM	field manual
FOD	foreign object damage
FOV	field of view
FSTC	Foreign Science and Technology Center
G or g	load factor
GSE	ground support equipment
GW	gross weight
hp	horsepower
HAC	helicopter air combat
HMD	helmet-mounted display
HMS	helmet-mounted sight
HSS	helmet sight subsystem
HUD	heads-up display
IAT	image auto tracker
ICS	intercom system
ID	Infantry Division
IFF	identification friend/foe
IHADSS	integrated helmet and display sight system
IR	infrared
IRIG	interrange instrumentation group
I_B	rotor blade mass moment of inertia, slug-ft^2
I_{xx}	body roll inertia
I_{yy}	body pitch inertia
I_{zz}	body yaw inertia
LED	light emitting diode
LN	lock number
LOS	line of sight
LWS	laser weapons simulator
M&A	maneuverability and agility
MAWTS	Marine Air Weapons & Tactics Squadron
MC	modernized Cobra
MCEP	maneuver criteria evaluation program
MDHC	McDonnell Douglas Helicopter Company
MEP	mission equipment package
MIPR	Military Interdepartmental Purchase Request
MOD	modernized
MOE	measure of effectiveness

Mq	rotor damping, 1/sec
NAS	Naval Air Station
NATC	Naval Air Test Center
NATOPS	Naval Aviator Training and Operations Procedures
NOTAMS	notice to airmen
N_r	rotor speed
N_x	longitudinal acceleration, G
N_z	vertical acceleration
PCM	pulse code modulation
PDU	pilot display unit
P_h	percentage chance of hit
P_k	percentage chance of kill
P_s	specific excess power
PLF	power for level flight
PNVS	pilot's night vision system
PNS	Polhemus Navigation Sciences
POL	petroleum, oil, lubricants
PROD	production
r	radius of rotor blade element, ft
R	radius of rotor blade, ft
ROE	rules of engagement
RPM	revolutions per minute
RTPS	Real-Time Telemetry Processing Station
RWATD	Rotary Wing Aircraft Test Directorate
SAS	stability augmentation system
SCAS	stability & control augmentation system
SIP	standardization instructor pilot
SLS	sea level standard
SOF	safety of flight
T	thrust, lb
TACTS	Tactical Air Combat Training System
TADS	target acquisition & designation system
TBD	to be determined
TM	telemetry
TRADOC	Training and Doctrine Command
TSD	Technical Support Directorate
TSU	telescopic sighting unit
USAAEFA	U.S. Army Aviation Engineering Flight Activity
USNTPS	United States Naval Test Pilot School
UTARNG	Utah Army National Guard
VFR	visual flight rules
VID	visual identification
VMC	visual meteorological conditions
V_{BE}	best endurance velocity

V_C	cruise speed
V_H	maximum horizontal speed with maximum continuous power
V_I	mean velocity between V_Y and V_C
V-n	velocity vs load factor
V_{NE}	not to exceed velocity
V-β	velocity vs slide slip angle
V_Y	horizontal speed at minimum power required
W	gross weight, lb
WTI	weapons tactics instructor
XMSN	transmission
σ	rotor solidity
τ	time constant, sec
ρ	density, slug-ft^3
ΩR	tip speed, ft/sec
Ω	rotor angular velocity, rad/sec